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January 1995

Crop Residue Management To Reduce Erosion and Improve Soil Quality

Southeast

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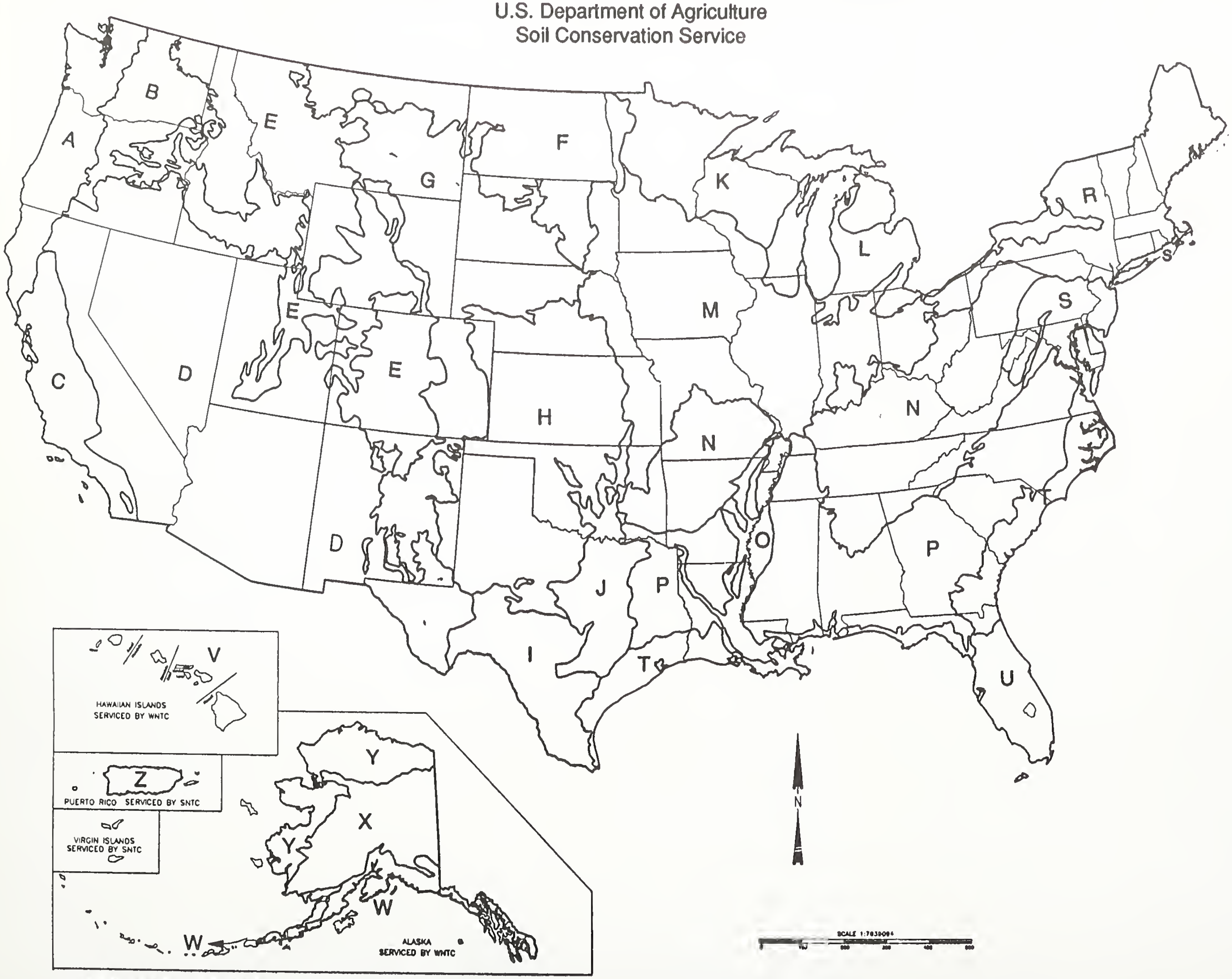
Crop Residue Management
Land Resource Regions of the United States

U.S. Department of Agriculture
Soil Conservation Service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Source: Map prepared using automated map construction. Albers equal area projection. National Cartography and Geographic Information System Center, Fort Worth, Texas 1993.

Resource Regions and Areas
as of January 1984
Land Resource Regions (LRR)

A	NW Forest, Forage and Specialty Crops
B	NW Wheat and Range
C	California Subtropical Fruit, Truck and Specialty Crops
D	W. Range and Irrigated
E	Rocky Mtn. Range and Forest
F	N. Great Plains Spring Wheat
G	W. Great Plains Range and Irrigated
H	C. Great Plains Winter Wheat and Range
I	SW Plateaus and Plains Range and Cotton
J	SW Prairies Cotton and Forage
K	N. Lake State Forest and Forage
L	Lake States Fruit, Truck and Dairy
M	Central Feed Grains and Livestock
N	East and Central Farming and Forest
O	Miss. Delta Cotton and Feed Grains
P	S. Atlantic and Gulf Slope Cash Crops, Forest and Livestock
R	NE Forage and Forest
S	N. Atlantic Slope Diversified Farming
T	Atlantic and Gulf Coast Lowland Forest and Crop
U	Florida Subtropical Fruit, Truck Crop and Range
V	Hawaii
W	S. Alaska
X	Interior Alaska
Y	Arctic and W. Alaska
Z	Caribbean Area

Major Land Resource Areas (MLRA)
MLRAs and number designation (see Agriculture Handbook 296)

January 1993 1007614

Crop Residue Management To Reduce Erosion and Improve Soil Quality

Southeast

G.W. Langdale and W.C. Moldenhauer, Editors

Abstract

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Leaving crop residue on the soil surface has a number of clear advantages over tillage that leaves the soil surface bare. Most notable is the greatly reduced erosion; this advantage alone makes the change worthwhile. Mandated conservation compliance by 1995 is a further incentive to adopt surface-crop-residue management. Other advantages are increased yield due to water conserved by surface residue; lower soil temperatures; higher quality soil over time due to increased soil organic-matter levels; and in many cases, reduced input of time, labor, and fuel.

The feasibility of surface-residue management has been proven by the increasing rate of acceptance and use by farm operators. Success is due in large part to the greater effectiveness and reduced cost of herbicides and the improvement of planting equipment available on the market. Farm operators and conservationists have formed associations and alliances for sharing experiences. Case studies, farmer experiences, and results of research helpful to farm operators have been published by chemical and equipment companies; the farm press; federal, state, and local governmental research and extension agencies; and private organizations.

Keywords: crop residue management (CRM), conservation tillage, reduced tillage, mulch tillage, surface residue tillage, fertilizer management, water quality, soil compaction, soil strength, CRM planting equipment, economics of CRM, soil-climate-tillage interactions in CRM, weed management, herbicides, insect pest management, plant disease management, winter cover crops, tillage long-term effects, CRM successes, erosion control, water-use efficiency

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Issued January 1995

This publication reports research involving pesticides. It does not contain recommendations for their use or imply that uses discussed here have been registered. All uses of pesticides must be registered by appropriate State or Federal agencies or both before they can be recommended.

While supplies last, single copies of this publication may be obtained at no cost from a local Soil Conservation Service District office. Copies may be purchased from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

This is one of six regional publications designed to report research results and the experience of experts in the field of crop residue management. The other regions are Appalachia and Northeast, North Central, Northern Great Plains, Northwest, and Southern Great Plains. Copies of the five other regional reports for *Crop Residue Management To Reduce Erosion and Improve Soil Quality* may be obtained from Conservation Technology Information Center, 1220 Potter Drive, Room 170, West Lafayette, IN 47906. Payment of postage and handling charges is required (fax 317–494–5969, telephone 317–494–9555).

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1 Introduction: Why the Emphasis on Crop Residue Management?

W.C. Moldenhauer and G.W. Langdale

Soil erosion by wind or water degrades our soils. Besides outrightly removing material from the fertile topsoil, large wind or rain storms selectively remove material that is high in organic matter and nutrients. This results in exposed subsoil that is depleted of plant-available nutrients, high in density, and low in porosity and capacity for water intake.

Recognizing the rapidity with which U.S. soils were degrading—especially on the 143 million acres of highly erodible lands—Congress passed the Food Security Act in 1985 to conserve our soils and ensure adequate food supplies for future generations. **The act sets a deadline of December 31, 1994, for full implementation of plans to control erosion on highly erodible lands if farmers are to maintain their eligibility for U.S. Department of Agriculture (USDA) program benefits.** When presented with the broad spectrum of available technologies at USDA Soil Conservation Service (SCS) offices, fully three-fourths of farmers concluded that the most cost-effective means for controlling erosion on their highly erodible lands was to keep more crop residues on the soil surface.

Any tillage and planting system that leaves all or some portion of the previous crop's residue on the soil surface is described as crop residue management by SCS and the Conservation Technology Information Center, West Lafayette, IN. Surface residue cover is known to greatly reduce soil erosion, even though the percentage required to adequately control erosion depends on the site and other conservation practices included in a total erosion-control system. As residue cover approaches 100 percent, soil erosion approaches zero; with 50 percent residue cover, erosion reduction is about 83 percent; with 10 percent residue cover, erosion reduction is still about 30 percent.

The southeast presents unique challenges in that the time of occurrence of high-erosion periods differs from those in other regions of the United States, and the decomposition of crop residues and the oxidation of organic matter are more rapid. These differences must be considered in order to develop cost-effective crop-residue management plans. Other goals of crop residue management in the southeast are to increase water infiltration and to time the residue cover to be effective during high-erosion periods.

Farmers' willingness to leave residue on the surface was greatly enhanced by the development of herbicides, which provided an alternative to tillage for controlling weeds. The efforts of equipment manufacturers and innovative farmers in developing equipment to leave more residue on the surface and then to plant through it have facilitated the availability and use of crop residue management.

The negative effects of crop residue, once looked on as far outweighing the benefits, are now seen as greatly overestimated, or else solutions have been found to make the negative results manageable. As the scientific, industrial, and farm communities persistently address the problems and find solutions, they approach the remaining problems more as challenges than as insurmountable disadvantages. This change of attitude has played a major role in accelerating the acceptance of crop residue management.

This publication summarizes research and experience that show the potential benefits and problems related to decreasing tillage and to leaving more residues on the soil surface. In the 16 chapters that follow, experts discuss the equipment, management practices, crop-protecting chemicals, crop rotations, cover crops, and cropping systems that enable farmers to control erosion on their lands—so they are in Federal conservation compliance—and also to optimize their net returns and improve the environment and natural resources.

This is one of six regional reports. Some of the technology is suited specifically to the climate and soils of particular regions. However, due to their recent and rapid development, not all of the potentially useful technologies have been tried in all regions. Consequently, some of the surface-residue management technologies used in other regions and discussed in the other five reports may apply to the southeast. A copy of these other regional reports may be obtained from Conservation Technology Information Center (see address and telephone number on abstract page).

There are a number of sources of information on all aspects of crop residue management. Included are publications of extension and research organizations; publications of chemical and equipment companies; farm magazines; and publications of organizations devoted especially to crop residue management. One recent publication with a great deal of information that is useful in all U.S. regions but especially in the midwest is MWPS–45, Conservation Tillage Systems and Management: Crop Residue Management With No-Till, Ridge-Till, Mulch-Till. This publication is available from MidWest Plan Service, 122 Davidson Hall, Iowa State University, Ames, IA 50011–3080. Another publication is Crops Residue Management, editors J.L. Hatfield and B.A. Stewart, published in 1994 by CRC Press, Inc., 2000 Corporate Boulevard, NW, Boca Raton, FL. Others especially for the southeast are the proceedings of southern conservation tillage conferences described in chapter 17 of this publication.

2 Terminology

D.L. Schertz and J. Becherer

In the early 1960's, the terms *minimum tillage* and *reduced tillage* were used to denote fewer trips over the field. These fewer trips may or may not have left residue on the soil surface after planting or during the critical wind erosion period. The terms did not quantify the surface residue left or any resulting reduction in erosion. The term *conservation tillage* also became popular. This term did imply that some surface residue was left but initially did not specify an amount.

In 1984, the Soil Conservation Service defined *conservation tillage* as "Any tillage and planting system in which at least 30 percent of the soil surface is covered by plant residue after planting to reduce soil erosion by water, or, where soil erosion by wind is the primary concern, at least 1,000 pounds per acre of flat small grain residue-equivalent are on the surface during the critical erosion period."

This definition remained through the early 1990's. The objective of conservation tillage was to leave surface residue to reduce the eroding forces of rain and wind.

Specific types of conservation tillage are no-tillage (also called no-till), ridge tillage (ridge till), and mulch tillage (mulch till). They are defined by the Conservation Technology Information Center as follows:

- **No-tillage.** The soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is done in a narrow seedbed or slot made by coulters, row cleaners, disk openers, in-row chisels, or rototillers. Weed control is done primarily with herbicides; cultivation may be used for emergency weed control.

- **Ridge tillage.** The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is done in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is done with herbicides or cultivation or both. Ridges are rebuilt during cultivation.

- **Mulch tillage.** The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used. Weed control is done with herbicides or cultivation or both.

These definitions have gained considerable acceptance. Even so, some confusion remains as to the meaning of conservation tillage. Research shows that surface residue of less than 30 percent may considerably reduce erosion even though, by definition, this amount is not considered conservation tillage.

Most farmers chose to comply with the 1985 Food Security Act to maintain eligibility for USDA program benefits. Many farmers selected practices that left sufficient crop residue on the surface to meet conservation goals. However, some of these tillage practices left less than the amount required. Some people considered conservation tillage to mean only no-till. It became clear that standard terminology was needed to clarify the impacts of leaving all or a portion of the previous crop's residue on the soil surface. The term *crop residue management* evolved to address the benefits of surface residue in reducing soil erosion.

The practice of crop residue management encompasses an entire cropping year as follows: (1) A crop is planted that will provide residue to meet a specified goal, such as keeping erosion within a specified limit. For instance, cover crops can be used along with low-residue crops. (2) At harvest there is good distribution of residue. This is an essential component. (3) The depth and speed of any tillage operation is carefully planned to maintain the desired amount of residue on the surface.

Crop residue management is defined as follows: Any tillage and planting system that uses no-tillage, ridge tillage, mulch tillage, or another system designed to retain all or a portion of the previous crop's residue on the soil surface. The portion required depends on other conservation practices that are included in the farmer's total conservation plan.

Throughout this publication, the terms *reduced tillage*, *minimum tillage*, *conservation tillage*, and *crop residue management* are used interchangeably. Each term refers to a system that leaves all or a portion of the previous crop's residue on the soil surface to reduce soil erosion to an acceptable level.

3 Description of the Region and Subregions

H.P. Denton, T.C. Keisling, G.W. Langdale, D.D. Tyler, J.E. Dean, and S.M. Dabney

Climate

Most of the southeast region is dominated by a temperate-humid climate and a moist (udic) soil-water regime (Buol 1973). Most warm-season annual crops that require a 200- to 260-day growing season, including cotton, are produced in this region. This long growing season can also be used to grow more than one crop per year, which provides viable opportunities for enhancing residue production. This climatic region lies generally at latitude 25°-37° N. and longitude 75°-97° W. Rainfall generally equals or slightly exceeds 50 inches annually. The accompanying rainfall erosion indices (ranging from near 200 foot-tons per acre-inch in the mid-Atlantic coastal area to 550 foot-tons per acre-inch along the Gulf of Mexico) are moderate to high (Wischmeier and Smith 1978).

Crop-residue decomposition rates are high but variable. These rates may be attributed to soil-temperature classes described in Soil Taxonomy (U.S. Department of Agriculture 1975). These classes provide subregionality and are referred to as mesic in northern latitudes to hyperthermic in southern latitudes. However, the thermic class dominates the southeast. These climatic variations are responsible, in part, for the wide range of Major Land Resource Areas (MLRA's) within this region (table 1). Multiple cropping with cool- and warm-season annuals is frequently used, producing up to 6 tons of crop residues per acre. Although the decomposition rates of these crop residues are variable among crop species and climates, most will decompose within a year.

Because of the climatic parameters described here, the management of crop residues is critical in the southeast for maintaining rainfall infiltration and control of soil erosion. Evapotranspiration usually exceeds summer rainfall. However, the climate in the southeast is a useful resource for the management of multiple-crop residues and subsequently soil water. Technology now in place or on the horizon will enhance the wise management of crop residues in the southeast.

Soils

Soils of the southern United States are highly weathered and acidic because of the age of the parent material and the warm and moist climate. The dominant soil order is Ultisol (Buol 1973). Ultisols are highly weathered mineral soils with low organic-matter content. Although their profile fertility status is considered poor, Ultisols can be made highly productive with the addition of fertilizer and lime and with appropriate surface-crop-residue management.

Less weathered soils that occupy significant crop acreage are Inceptisols (MLRA 131, Southern Mississippi Valley Alluvium) and Alfisols (MLRA 134, Southern Mississippi Valley Silty Uplands). These soil orders occupy about 254 million acres in this region.

Eleven southern U.S. states are included in O, P, T, and U Land Resource Regions (see map in cover pocket). Almost all these soils have restrictive subsoil layers. However, they are moderately weathered without excessive depletion of organic matter, calcium, magnesium, or potassium.

Cropland occupies about 41 million acres in these southeastern states. This is approximately 10 percent of the U.S. cropland acreage. About 13 percent of the 41 million acres has been introduced to no-tillage. The soil erodibility of these soil orders is moderate to high. The soil erodibility factor, K ($K = A/EI$), used in the Universal Soil Loss Equation (USLE), ranges from near 0.25 to 0.40. The USLE-estimated soil erosion rate approaches or exceeds soil loss tolerance (T) in important cropland MLRA's (table 1). The USLE-predicted soil losses in association with the high average C factor (cover and management factor, both canopy and crop residues) provide signals of potential soil-erosion hazards. The signals suggest that considerably more land is experiencing degradation from conventional tillage than is experiencing aggradation from wise crop-residue management practices.

Important physiographic divisions are the Atlantic and Gulf Coastal Plains, the Southern Piedmont, and the Mississippi Alluvial Valley. The Southern Coastal Plain (MLRA 133A) includes Atlantic and Gulf coastal regions of the United States. Dominant soils are Udults with thermic (warm) temperature and udic moisture regimes giving rise to kaolinitic clay mineralogy. They are moderately to well drained, have low organic matter, and are moist with loamy or sandy surface layers over a loamy or clayey subsoil. The compacted E horizon (10–14 inches deep) must often be fractured with an in-row subsoiler following a coulter to allow root penetration.

The Western Coastal Plain (MLRA 133B) soils are also mostly Udults. However, they are deep, with coarse-textured topsoil over moderately coarse-textured to fine-textured subsoils. They also have thermic temperature and udic moisture regimes but siliceous or mixed mineralogy.

The Southern Piedmont (MLRA 136) is also Udult dominant with thermic temperature and udic moisture regimes. Mineralogy is kaolinitic, mixed, or oxidic. Topsoils are usually more eroded into clayey or loamy subsoils than are adjacent Coastal Plains soils. Restrictive zones usually occur in the top of these subsoils and severely inhibit rainfall infiltration.

The alluvial Inceptisols (MLRA 131) are, for the most part, deep with high natural fertility. Some are either clayey or sandy and, although deep, do not usually have a very large rooting volume due to other root-restricting characteristics. Many of the soils in the region have a very high silt content, have had the organic matter "oxidized" out or eroded away with the topsoil, and often have a severe crusting problem. These soils, when managed to overcome constraints, are some of the most productive in the southern United States. These soils vary widely in textural and chemical characteristics. The classification of soils of MLRA 131 range from Alfisols to Inceptisols (young soils with rock at shallow depths) to Entisols (young soils without distinct horizon development). Small areas of Histosols (peats and mucks) and Mollisols (dark-colored and rich in calcium, potassium, and magnesium) also occur. The alluvial nature of the region often results in fields that range from well drained to poorly drained and also from sand to loam and/or clay.

The Southern Mississippi Valley Silty Uplands (MLRA 134)—consisting of loess-derived soils in Kentucky, Tennessee, Mississippi, and Louisiana—have very high soil erosion rates, ranging from 15 to over 25 tons/acre/yr (Langdale et al. 1985). These Alfisols are characterized by fragipans in over 50 percent of the highly erosive upland soils. In some areas (for example, Fayette County in western Tennessee), fragipans are present in about 70% of the uplands. Fragipans are naturally occurring, root-restrictive subsoil horizons (U.S. Department of Agriculture 1975). The use of conventional tillage has accelerated erosion and has been particularly detrimental on the shallow soils that overlie root-restrictive fragipans.

All MLRA soils described here suggest that an important technique is double cropping with cool- and warm-season annuals. These annuals are often no-till drilled directly into perennial cool- and warm-season sods. Recent conservation tillage successes in both research plots and innovators' farms indicate that substantial potential benefits can be derived from managing crop residues with no tillage on all MLRA's discussed here.

Crops and Rotations

The spectrum of possible agronomic crops is very wide on southeastern soils, primarily because of the climate. Sugarcane, rice, tobacco, peanuts, cotton, feed grains, oil crops, and perennial seeds provide many rotation options. Horticultural crops, such as melons, sweet corn, and lima or green beans, are often rotated with agronomic crops. Double cropping offers some frequent crop-rotation approaches and no-tillage alternatives. Sod-based or hay/grazing crops (for example, fescue, bermudagrass, and bahiagrass) are dominant perennial crops of Alfisols and Ultisols (MLRA's 133 through 152). Research and past experience suggest that these sod-based crops are excellent precursors to conservation-till row crops; thus they can become pivotal rotating crops when supported with appropriate land stewardship and marketing policies.

Feed grains and soybeans are most important for the O, P, and T (table 1) Land Resource Regions when their market prices are near cycle peaks. Currently, cotton is becoming the dominant no-tilled row crop of the southeast. Peanuts, rice, tobacco, sugarcane, and horticultural crops occupy smaller acreage and are not as amenable to no-till management. Only recently have research efforts provided adequate technology for the successful management of crop residues for no-tilled cotton. The rotation of small-acreage and high-profit crops with acceptable residue management remains a research and management challenge. Accompanying the thermic and hyperthermic climates (high average temperatures) in the southeast are increased weed and pathogen pressures, and there is a great need for frequent crop rotations to help control these pressures. But because of volatile markets and reasons expressed here, a crop-rotation prescription for most MLRA's is difficult to follow.

Crop rotations on alluvial soils (MLRA 131) are more consistently productive, although many fields have been continuously planted to cotton for over 100 yr.

However, the average cover and management factor (C = 0.33) is one of the highest of all MLRA's of the southeast (table 1). The average USLE soil-loss-tolerance limit (T value) is 4.4. The concentration of cotton (no rotation with other crops) on the best soil types of this MLRA remains a deterrent to improved residue management. When high-residue crops are rotated with cotton, the carryover of residues provides more crop residue to help control erosion. Rice is usually grown in rotation with soybeans in either 1 yr of rice to 1 yr of soybeans or 2 yr of rice to 1 yr of soybeans. Most wheat is double cropped with soybeans or grain sorghum. On nonirrigated land, grain sorghum is commonly grown in a rotation of 1 yr of grain sorghum to 2 yr of soybeans. Corn is used similarly to grain sorghum but is grown on more productive or irrigated land. A substantial acreage is cropped continuously with soybeans. Peanuts are almost always rotated with corn, cotton, and grain sorghum.

Sugarcane presents unique soil-conservation problems. Sugarcane management also varies greatly across the southernmost part of the United States (Texas, Louisiana, Florida, and Puerto Rico). In Louisiana (MLRA 131), sugarcane lands are usually managed in a 4-yr cycle. The first crop is harvested 12–13 mo after planting, followed by two 1-yr ratoon-regrowth crops and finally 11–14 mo of fallow to control weeds and diseases. Although the land is typically graded to less than 0.2 percent slope steepness, erosion from these bedded lands can be serious when the soil is not protected by residue or canopy cover (Barnett et al. 1978, Murphree and Mutchler 1981). With normal sugarcane culture, land is left exposed for 18–21 mo from the time second-stubble cane is plowed out, in late fall or early spring, until freshly planted cane creates a canopy in July of the following year.

Some farmers have grown crops of winter wheat or early-maturing soybean during this period, but success requires favorable weather, suitable equipment, and careful management. A less intensive residue-management alternative is similar to the stale-seedbed approach being adopted by soybean and cotton farmers in the Mississippi Delta. In this system, after plowing out or disking the old cane, subsoiling if necessary, and reversing rows, the beds are rebuilt in their original positions. Weeds or planted cover crops are then allowed to grow to provide cover, and are controlled with glyphosate prior to seed formation. Johnsongrass is controlled with herbicides rather than with six to eight tillage passes in summer. Beds may be knocked down and re-hipped just before planting cane in September; a cover crop can be seeded at that time and allowed to grow until March or April.

With rice cropping rotations, residue will arise from the rice stubble and from its rotation crop—usually soybeans. Essentially all rice produced in the Mississippi Delta Cotton and Feed Grain Region is paddy rice. Remnants of levees left in paddy fields often impede surface drainage of the fields so that they are still wet at harvest time and become deeply rutted during harvest operations. Conventional rice-residue management consists of mixing rice straw with soil to enhance decomposition before the next cropping system or tillage operations. Ordinarily levees are plowed out at harvest or in late winter or early spring, when the fields are usually disked to smooth the ruts left from the harvest operation. Residue from the crop rotated with rice is usually incorporated into the soil before planting rice in early fall, and the land is floated if possible. The interval between herbicidal weed burndown and planting should be about 14 days to allow sufficient decomposition of stubble to discourage seedling diseases. This is especially critical when rice is water seeded rather than drill seeded with no mechanical seedbed preparation. Some farmers have used a no-till system of seeding rice directly into the soybean stubble. This practice results in a substantial saving in production cost and gives the farmer control of red rice problems.

In wheat-cropping systems, residue arises from the wheat, and soybeans are usually double cropped. The conventional manner of managing wheat residue in the southeast region is to burn, disk, apply a herbicide, and plant soybean. Farmers usually burn crop residue to facilitate tillage. But modern technology allows the discontinuance of this practice, which will result in increased organic matter and physical properties that improve water infiltration and soil tilth. The practice of burning the wheat residue is finally beginning to be replaced by no-till planting directly into the wheat residue. Currently, the most important factor that inhibits no-tilling into the wheat stubble is the high cost of weed control under heavy weed pressure, compared to the cost of using preplant incorporated herbicides. The soybean stubble is usually disked twice before planting wheat in the fall. Some farmers are now successfully no-tilling wheat into soybean stubble.

Pathogen and weed pressures are the most important reasons for rotating crops on soils in the southeast. However, national farm policies and markets often deter the rotation of crops in this region.

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Table 1. Erosion risk of cropland in southeastern United States, by Major Land Resource Area (MLRA)

Major Land Resource Area	Total area (million acres)	Total cropland (1,000 acres)	Conserv. tillage (1,000 acres)	Aver. USLE soil loss (tons/acre/yr)	Relative erodibility (USLE C factor)
P. South Atlantic Gulf Slope Cash Crops Forest and Livestock Region (175.6 million acres)					
133A. South Coastal Plain (MS, AL, GA, FL, SC, NC, VA)	70.4	12,823.0	1,493.8	5.5	0.26
133B. Western Coastal Plain (TX, AR)	34.8	505.6	91.3	3.8	0.42
134. Southern Mississippi Valley Silty Uplands (MS, TN, AR, LA)	18.3	4,179.1	572.0	11.7	0.23
135. Alabama, Mississippi, and Arkansas Blackland Prairie (MS, AL)	5.3	870.6	161.2	6.7	0.19
136. Southern Piedmont (AL, GA, SC, NC, VA)	39.9	3,933.7	588.2	10.7	0.26
137. Carolina and Georgia Sand Hills (GA, SC, NC)	5.6	601.4	7.7	5.3	0.20
138. North Central Florida Ridge (FL)	0.8	315.9	0.0	1.3	0.23
T. Atlantic and Gulf Coast Lowland Forest Crop Region (61 million acres)					
150A. Gulf Coast Prairies (TX, LA)	10.3	4,598.9	463.9	2.2	0.27
150B. Gulf Coast Saline Prairies (TX)	3.2	144.5	0.0	1.5	0.21
151. Gulf Coast Marsh (LA)	5.2	51.2	0.0	2.6	0.09
152A. Eastern Gulf Coast Flatwoods (MS, AL, FL)	4.2	218.0	5.5	3.6	0.27
152B. Western Gulf Coast Flatwoods (TX, LA, VA)	4.2	260.8	11.9	2.9	0.28
153A. Atlantic Coast Flatwoods (FL, GA, SC, NC)	18.2	3,322.6	185.4	3.2	0.19
153B. Tidewater Area (SC, NC, VA)	7.7	1,068.2	223.3	1.7	0.18

O. Mississippi Delta Cotton and Feed Grain Region (23.1 million acres)*					
131. Southern Mississippi Valley Alluvium (LA, MS, AR, TN)	23.1	7,341.0	1,669.8	4.4	0.33
U. Florida Subtropical Fruit, Truck Crop, and Range Region (23.4 million acres)					
154. South Central Florida Ridge (FL)	6.0	262.2	42.9	1.5	0.26
155. Southern Florida Flatwoods (FL)	13.6	280.2	1.1	1.2	0.18
156A. Florida Everglades and Associated Areas (FL)	2.8	409.0	0.0	0.2	0.10
156B. Southern Florida Lowlands	1.1	49.9	0.0	0.0	0.37
TOTAL	274.7	41,235.8	5,518.0	---	---

* Includes 5.6 million acres in Crowley's Ridge in Land Resource Region O, MLRA 134 (U.S. Department of Agriculture 1981)

SOURCE: Estimates based on 1987 National Resources Inventory, Soil Conservation Service, USDA.

4 Description of Surface-Residue Tillage Systems in Use

G.W. Langdale, T.C. Keisling, D.D. Tyler, J.E. Dean, and S.M. Dabney

The P Land Resource Region (Ultisols and Alfisols), which dominates the southeast region (see ch. 3), suffers considerable soil erosion (table 1). The average C factor for Major Land Resource Areas (MLRA's) in this Land Resource Region indicates inadequate residue management. Estimates of conservation-tillage acreage by the National Resource Inventory (U.S. Department of Agriculture 1987) and the Conservation Technology Information Center for southeastern states are presented in table 2. Acreage of conservation tillage has increased each year since 1984 except for 1990 and 1991, when the lows were associated with droughts and commodity market crashes. A surge in no-till in 1992 was the major contributor to the conservation-tillage increase.

Diverse residue-management systems of the southeast are closely associated with profile characteristics of the soils in these MLRA's. Fluted coulters are an acceptable tool for cutting through residues to allow seed placement on silt-loam soils next to the Appalachian region as well as on loessial and Delta soils (MLRA 134). Restrictive horizons of the Southern Piedmont (MLRA 136) and the South Atlantic and Gulf Coastal Plains (MLRA's 133A/B and 137) often require in-row chisel or subsoiling (or slit tillage) to facilitate more rapid infiltration of rainfall and to improve deep plant rooting into the Bt or E horizon and thus achieve economically acceptable crop yields. Discussions in this chapter of improved crop residue management related to warm-season-crop production of MLRA's 133A/B, 136, and 137 involve slit tillage unless specified differently. In-row shanks of slit-till planting operations follow coulter slits. These shanks are now equipped with 1.5-inch-wide points. Restrictive soil layers shattered by this equipment are 7–14 inches deep. Paratill implements are now designed to perform at a similar depth range. In the other MLRA's, surface-crop-residue management can generally be accomplished with coulters. A major disadvantage of the slit-till systems is the increased cost of machinery and fuel. Recent research on Southern Piedmont soils involving intensive, long-term surface-residue management suggests that deep tillage may not always be necessary (Langdale et al. 1990, 1992). After soil improvement with intensive double-crop residue management for several years, infiltration rates remain high and rooting depths can be satisfactory without deep tillage.

Another dimension of southeast no-tillage is associated with cool-season crops. In the southeast, this involves the growth of winter legume and grain crops. No-tilling of cool-season annuals increased exponentially following 4 yr of severe summer droughts and market crashes in the late 1980's.

Perceived disadvantages of crop residue management in the southeast are often associated with the cost of equipment and pesticides. The cost of adaptable conservation-tillage equipment varies among MLRA's but seldom exceeds the cost of an offset disk harrow and secondary tillage equipment. The equity of conservation-tillage equipment on Ultisols depreciates rapidly unless the cost of repairing soil-engaging parts is minimized. Current research in the southeast also reveals that the rotation of herbicides while crops are rotated will reduce weed escapes and the cost of these farm chemicals. Rotations also minimize the development of herbicide-tolerant weeds.

Cotton-insect management in various areas of the southeast requires different residue managements. For instance, in the Carolinas and Georgia, cotton stalks must be shredded before January to comply with the boll-weevil-eradication program. In Arkansas, cotton stalks must be shredded by April 15 for control of pink bollworm.

Recently, farmers have begun to plant more cover crops and to reduce preplant tillage. Cover crops used the most are vetch, wheat, and rye. Contour farming, terraces, grassed waterways, and so on, together with winter cover crops (primarily vetch) have been used on the Rodney Bryant farm in St. Francis County, Arkansas, for at least 30 yr. In dryland cotton production in droughty years, this farm consistently produces 300–400 more pounds of lint per acre than do neighboring farms on similar soil types.

Some Arkansas farmers began using wheat and rye cover crops in 1989 together with a ridge-till system. This system has worked very well in halting wind damage to young cotton seedlings. Growers have reduced preplant tillage to one trip to bar off the beds and incorporate herbicides in a band on top of the row. The middles are mechanically cultivated.

Sugarcane-residue management presents unique problems because of the burning of the dry leaves during preharvest or harvest periods. This practice is gaining more global publicity as an air-pollution hazard than as poor residue management. Sugarcane researchers and growers are credited with few soil-conservation accomplishments, but sugarcane growers in Australia have successfully conservation-tilled since the mid-1980's with minimum research support. They credit successful ratoon crops to heavy mulch blankets of sugarcane residues.

Most southeastern states produce a wide spectrum of vegetable crops. This farm activity accounts for more than 30 species on 200,000 acres or more in each state. Similar to sugarcane management, most of these row-crop management systems leave little residue on the soil surface. Vegetable crops and sugarcane deserve considerable residue-management research.

Rye is often grown as a cover crop but is not harvested for grain. Its advantages over wheat as a cover are more fall growth, rapid spring growth, and slower decomposition of the mulch. Rye is also a good scavenger for soil nitrate nitrogen; this can be a disadvantage because of the excessive residue that can result if the rye is not killed on a timely basis. Extensive growth of rye near warm-crop planting time can also deplete soil-water supplies.

For winter annual cover crops, the canopy development and subsequent soil protection from legumes are not as rapid as those from some grasses. But legumes do provide other advantages such as biological fixation of nitrogen for use by subsequent crops, rapid decomposition and conversion to soil organic matter, recycling of nutrients, and little immobilization of nitrogen, which can occur to some degree with grass cover. Data from numerous experiments in the loessial soils of Tennessee indicate that legume cover crops after grain crops contribute 50–70 lb nitrogen per acre. This reduced need for fertilizer nitrogen helps cover the expenses of establishing the cool-season winter annual legume cover. Because of the importance of winter cover crops in the southeast, chapter 14 is devoted to these crops.

Information needs associated with crop residue management in the southeast include the operation of optional equipment on soils with restrictive horizons as well as on various erodible soil surfaces. A prime example of equipment is the paratill. Researchers are only beginning to present results associated with the opposing right- and-left-shank design. The optimal frequency and seasonal use of this tillage tool are not yet known because some of the results of such tillage are not immediately apparent.

The appropriate acceptance of such tools can be facilitated by custom entrepreneurial management similar to custom combining in the Great Plains states. Considerable expertise in crop residue management can be developed by custom operators. Because of more "degree days" in a humid environment, the control of weeds, pathogens, and insects poses the greatest knowledge gaps for surface-crop-residue management. Although these gaps are addressed here in later chapters on weeds, insects, and diseases, crop rotations may be the most environmentally prudent approach to solve these problems.

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Table 2. Conservation tillage cropland in southeastern United States (in 1,000 acres)

State*	1984	1989	1991	1992
Alabama	738	365	290	389
Arkansas	163	464	630	644
Florida	172	49	30	53
Georgia	1,194	879	582	648
Louisiana	448	309	545	564
Mississippi	650	843	914	1,170
North Carolina	1,923	718	689	805
South Carolina	195	195	147	199
Tennessee	1,516	990	1,174	1,526
Texas	2,228	4,036	3,715	4,077
Virginia	1,079	959	931	818
Total	10,306	9,771	9,647	10,893

* These states include most of Land Resource Region P which includes most of the conservation tillage in the southeast.

SOURCE: Conservation Technology Information Center, West Lafayette, IN.

5 Interactions of Surface Residue With Soil and Climate

G.W. Langdale, T.C. Keisling, D.D. Tyler, and S.M. Dabney

The Major Land Resource Areas (MLRA's) in the southeast (see table 1 in ch. 3) are diverse and thus require various kinds of winter cover crops and tillage technology. Accordingly, the crop residue types and the tillage technology to manage these residues are extremely variable. Moreover, variations in climate in the southeast often result in various pests and pathogens that affect crop-residue production and management.

In the southeast, long-term crop rotations are often the most effective management for breaking the survival cycles of diseases and insects that can become problems in monocrop systems when crop residues are left on soil surfaces (Langdale et al. 1990). Unfortunately, national farm policies and commodity price-support programs tend to inhibit the effective use of sound crop rotations.

After 10 yr or more, crops such as fescue, bahiagrass, coastal bermudagrass, alfalfa, and sericea lespedeza develop excellent sods to rotate with warm-season row crops (Carreker et al. 1977). The Conservation Reserve Program (CRP), which incorporated 10 yr of grass into lands in other regions of the United States, resulted primarily in increased pine tree production in much of the southeast. In addition to soil cover for erosion control, these long-term cropping systems increase the organic matter and soil biological activity, which in turn enhance the rainfall infiltration and subsequently the crop yields. Options for following CRP contracts are discussed in chapter 15. The best management for the conservation or enhancement of eroded sloping soil with long slope length generally includes a perennial forage crop in the rotation system. Similar cropping or tillage systems are essential for the successful management of Entisols (Carolina and Georgia Sand Hills, MLRA 137) and the sand ridges of Florida (MLRA 138 and 154).

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6 Effects of Surface Residue on the Conservation, Availability, and Use of Water

T.C. Keisling, G.W. Langdale, and D.D. Tyler

Crop-residue management research involving soil and water conservation on southeast soils has been oriented toward increasing rainfall infiltration during the growth of warm-season crops. Considerable research has been conducted to measure rainfall runoff and soil-water content, which allowed estimates of water infiltration, evaporation, and water-use efficiency.

Studies by Wagger and Cassel (1993) from MLRA 136 in North Carolina on Ultisols showed that the water-use efficiency for corn grain averaged about 470 lb/acre/inch for conventional management and about 508 for no-tillage management. For corn silage, they reported average water-use-efficiency values of 626 and 861 lb/acre/inch for conventional and no-tillage management, respectively. Water-use-efficiency research on MLRA 133A also suggested that values from conventional-tilled corn were considerably lower than those from no-till corn (Camp et al. 1988).

Rainfall infiltration and root-zone storage are essential on southeast soils and are critical on eroded Alfisols and Ultisols. Keeping crop residues on the surface with no tillage on these soils has resulted in the greatest improvement in soil and water management of the century. The conservation of soil water during high-evapotranspiration months increases crop yields and diminishes excessive runoff and accompanying soil losses. Cool-season-crop residue production is also needed to achieve enhancement on moderately to severely eroded soils (Langdale et al. 1992b). Because of excessive runoff from bare soils, warm-season-crop production (monocropping) on eroded soils using conventional tillage is not practical. The presence of cool-season-crop residues on the soil surface helps get the needed water into the soil during the summer and reduces evaporation from the soil.

Intensive double cropping on eroded Ultisols produces sufficient quantities (5 tons/acre/yr) of crop residues to create significant soil biological changes and subsequent soil physical changes. These changes become apparent after 3-5 yr of double-crop no-tillage (Langdale et al. 1990). Increased soil organic matter is accompanied by increases in water stable aggregation and infiltration (Bruce et al. 1992, Langdale et al. 1992b). On a Southern Piedmont watershed, runoff was reduced from an average of 10 inches (conventional tillage) to 0.5 inch (conservation tillage) annually over a 10-yr period (Mills et al. 1988). After almost two decades of double-crop no-tillage on the same watershed, the 90 tons or so of crop residue that had been returned to the soil surface reduced runoff significantly, even during major storms (Langdale et al. 1992a).

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7 Economics of Surface-Residue Management

E.H. Hudson and J.F. Bradley

Before no-tillage farming became a common practice, farmers relied primarily on forage crops in systems of long rotations or on terraces and waterways to shift from a nonconservation to a conservation farming system. But the potential income from forage crops is generally lower than that from row crops, and the potential yield increase from using forage crops in rotations is a benefit realized only over time. As for mechanical soil structures, they are expensive to construct and they require maintenance. Also, crop yield is generally reduced in the short run in areas from which soils have been borrowed for construction purposes. Thus, both alternatives normally mean reduced net farm income in the short run. No-tillage farming is generally an economically superior alternative because it reduces erosion and, at the same time, has the potential to increase net farm income (Hudson 1993).

Cost Comparisons of Soybean

Some producers suggest that it costs more to manage crop residues on the soil surface than to conventional-till, whereas other producers suggest the opposite. Who is right? Both are; it depends on the costs considered and whether or not there are problem weeds in the particular field.

Variable costs per acre for no-tillage soybeans and for conventional-tilled soybeans without major weed problems are $82.00 and $88.83, respectively. Variable costs for cotton and corn are about $3 less per acre for no-tillage. The fixed costs—interest on machinery and depreciation—are about $20 per acre less for no-till than for conventional till.

If problem weeds such as rhizome johnsongrass and marestail are present, then the variable cost of no-tillage will be slightly higher than that of conventional till. However, if fixed costs are included, no-tillage has the lower total cost.

Comparison of Yields

Research in Tennessee and other states shows no significant difference in the yields of corn, cotton, soybeans, and grain sorghum under no-tillage versus conventional tillage on well-drained to moderately drained soils. The 10-yr average yields of these crops have been slightly higher for no-till. Long-term no-till farmers claim greater yields due to increasing soil organic matter and increased infiltration compared to yields from conventional-tillage systems. Yields of long-term no-till continuous corn tended to be about 10 percent lower than those on conventional-tilled plots in Kentucky in the first few years of the comparison, but generally exceeded the conventional-till yields by 10–20 percent in the second 10 yr of the comparison (Ismail et al. 1994).

More Intensive Use of Resources

Farmers are becoming more concerned about soil erosion. They are aware that excessive soil losses will result in higher production costs and lower crop yields. This translates into a reduction in net farm income. No-tillage not only has the potential to reduce the costs of production and improve the yields, but also can reduce the erosion to acceptable levels. A complete conservation farm plan is needed to properly analyze the economic aspects of no-tillage.

The following example is a small Resource Management Cooperator (Tennessee Valley Authority) farm in western Tennessee. The farm consisted of 267 acres of open land, which are classified in table 3. The crop rotations shown in table 3 meet soil loss tolerance. Based on current budgets, this crop program has a projected net return to land, labor, capital, and management of $14,860.

With no-till it was possible to eliminate wheat and lespedeza—normally lower profit crops than corn and soybeans—from the crop program. Using the same crop yields for no-tillage and conventional till, the projected net return to land, labor, capital, and management increased from $14,860 to $23,340. Adding no-tillage increased the annual income by $8,480. Lower production costs under no-tillage and more intensive use of the land account for the increase.

Lower production costs for no-tillage account for only $1,192 of the $8,480 increase. More intensive land use made possible by switching wheat and hay to no-till corn and soybeans accounts for 86 percent ($7,288) of the difference in the two systems.

Expansion of Operation

No-tillage requires less labor than conventional tillage and also permits expansion of the operation with the given labor supply. Assuming the producer can rent additional land, the farming operation can be expanded by 136 acres of corn and soybeans using conservation tillage on 272 acres. Under a one-fourth crop-share lease, the net return to the operator's labor and capital is usually $30 and $35 per acre of soybeans and corn, respectively.

The overall effect of adding no-tillage in the same example is as follows (adapted from Hudson 1993):

	Expansion of rented land	Percent of total
Reduced production costs	$1,192	9
More intensive resource use	7,288	57
Expanded operations:		
Rent 136 acres	4,420	34
Total	$12,900	

Note that the more intensive use of land resource and the expansion made possible by reduced labor requirements contribute over 90 percent of the increased income. Even if no-tillage has slightly higher costs and lower crop yields than conventional tillage, no-tillage can still show a higher net return.

To answer the ultimate question of whether no-tillage has a place on a particular farm, a complete conservation farm plan should be developed.

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Table 3. An example of use of land resources

Acreage	C factor*	Potential use with conventional tillage
56	.300+	Corn-soybeans
98	.160	Corn-drilled soybeans-wheat-lespedeza
113	.100	Drilled soybeans-wheat-lespedeza

* C is the factor representing relative effects of specific rotations on soil erodibility.
SOURCE: Hudson (1993).

8 Fertilizer Management

J.T. Touchton, D.W. Reeves, and C.W. Wood

Plant nutrient requirements are established by genetic characteristics of the plant, and theoretically, these requirements should not vary among tillage systems. However, fertilizer management practices and the ability of the soil to provide nutrients will vary among tillage systems. These variations are due to changes in soil physical and chemical properties and to concomitant changes in the speed of chemical and biological reactions, as tillage systems are altered from the more conventional systems (disk-plow-disk before planting with postemergence cultivation for weed control) toward complete no-tillage systems. Therefore, fertilizer recommendations—based on soil test levels and on crop needs—that were developed primarily from research conducted with conventional-till practices are not necessarily viable for reduced-till systems.

There are definite differences between fertilizer-application methods for the two systems. With conventional tillage, surface applications of fertilizers are mixed with the upper 6–8 inches of soil, and nutrients that are usually applied after crop emergence are applied to the residue-free soil. In conservation-tillage systems, mixing nonmobile nutrients with the surface soil and applications of fertilizers to a residue-free surface are not always an option. When tillage is avoided completely and nonmobile nutrients are broadcast on the surface, there was concern that the nutrients would remain "stratified," with high concentrations in the top inch or two of soil and little or none in the lower portion of the root zone. However, crop yields have not appeared to decline as a result of surface fertilizer management.

Application of Phosphorus, Potassium, and Lime

Much of the initial fertilizer and fertility management research in no-tillage systems was designed to address concerns about stratification of nonmobile nutrients and soil pH levels that result from surface applications of fertilizers and lime. Although analyses indicate that stratification does occur and can be rather striking, there are no strong indications that this stratification adversely affects crop yields.

Based on information from several experiments, surface applications of fertilizers will maintain crop yields in no-tillage systems even if soil fertility levels are not adequate at lower soil depths. This approach has been used successfully in perennial pastures for years. Some growers alternate fields in which soil-mixing implements are used, but others use continuous no-tillage for many years. These planned tillage rotations or lack of rotations should be considered when planning maintenance applications of fertilizer and lime. The depth of soil sampling for fertility maintenance should be from the surface few inches of soil in fields where no deep mixing of soil will occur. If plans are to use deep-tillage implements that thoroughly mix the soil, then soil samples should be taken down to the planned depth of tillage, and fertilizer should be applied just before tillage. Regardless of the approach used, soil-testing laboratories should be made aware of the sampling depth and the planned soil-mixing depths so that they can adjust their calibration and recommend optimum application rates. Most soil-testing labs base their recommendations on the depth of incorporation.

The soil pH level will stratify in soils in which tillage implements that mix the soil are not used. There is also information (for example, see ch. 16 on long-term effects) suggesting that surface applications of lime without incorporation can adequately maintain soil pH levels. The greatest hazard associated with liming recommendations in no-tillage systems is associated with soil sampling depths.

Surface applications of acid-forming fertilizers—especially ammonium and urea forms of nitrogen—can rapidly decrease soil pH in the surface few inches of soil and result in stratification of pH levels in the top 6–8 inches of soil. Thus, the pH of a soil sample taken at a 6- to 8-inch depth may indicate that soil pH levels are adequate, and as far as plant growth is concerned, the pH may indeed be adequate. However, low pH at the soil surface reduces the activity of some herbicides. To ensure that pH at the soil surface is adequate, a shallow sample (upper 2 inches) should be taken periodically when continuous no-tillage is used. With the surface samples, it is important that lime recommendations not be based on a soil-mixing depth of 6–10 inches; growers should ensure that soil-testing labs are aware of the depth at which soil samples were taken.

Nitrogen Fertilizers

The selection of nitrogen fertilizer rates, sources, and application methods definitely require management decisions in no-till systems that differ from those used in conventional-till systems. Although source selection and application methods may be more critical than rate selections when comparing conventional-till with no-till, the nitrogen rate needed for optimum yield will vary among tillage systems. This variation is attributed, in part, to the quality of crop residues returned to the soil surface. When crops are grown in both the cool and warm seasons and include legumes, sizeable quantities of nitrogen are mineralized, decreasing the synthetic-nitrogen requirements. In addition to reducing synthetic-nitrogen needs, the use of crop rotations and rye cover crops—or other cool-season nitrogen scavenger crops—may help prevent the leaching of nitrate and the associated degradation of groundwater.

Since differences in nitrogen fertilizer requirements among tillage systems are not easily identified, the nitrogen rates commonly recommended for a specific crop should be used. Selections of nitrogen source and application method must be considered as a coordinated management practice. It is difficult to inject or incorporate nitrogen fertilizers in many no-till systems, but it can be done with some of those systems. In addition, injection systems are available that can inject nitrogen into most tillage systems. Most injection systems are designed to inject nitrogen midway between the rows; but on some soils, injection next to the row is preferable. For instance, in soils that are highly compatible such as sandy coastal plain soils, the crop roots may not reach the row middles, especially in tire-traffic middles. Do not assume that no-tillage will eliminate compaction problems.

After crop emergence, surface applications of nitrogen fertilizer are the most practical method available for many no-till systems. Nitrogen sources commonly available are prilled ammonium nitrate, prilled urea, and various nitrogen solutions. A key point to remember is that volatilization losses will not likely occur with surface-applied ammonium nitrate but can be appreciable with surface-applied urea. Several nitrogen solutions are available; those frequently available are 19, 21, 28, 30, and 32 percent nitrogen. The 19-percent solution is either ammonium nitrate or a byproduct. The byproducts can be a mixture of many sources. The solutions containing 21 percent or slightly higher nitrogen concentrations are generally 100 percent urea nitrogen. Those containing 28, 30, and 32 percent nitrogen are about 50 percent urea-nitrogen and 50 percent ammonium nitrate-nitrogen. The volatilization properties of nitrogen in solutions are very similar to those of nitrogen in solid materials, which means that urea in solution can volatilize as readily as prilled urea. These potential losses should be considered along with the lower prices generally associated with urea-containing fertilizers. The long-term effects of the surface application of lime and fertilizers are discussed in chapter 16.

Some basic guidelines for the selection of nitrogen source and application methods in no-till systems are as follows:

1. If the price of ammonium nitrate or another nitrogen source that is not likely to volatilize (such as sodium nitrate) is comparable to the price of urea or urea-containing solutions, use these sources instead of urea. Cost comparisons should be based on cost per pound of nitrogen and not cost per pound of material.

2. Application methods are not critical for ammonium nitrate. It is probably best to band the fertilizer next to the row rather than to broadcast the material. It is not prudent to fertilize weeds in the row middles or to fertilize where crop roots may not be growing.

3. If possible, do not band apply fertilizer in the row middles. If nitrogen must be applied to the row middles, it should be applied to those that have not been compacted with tractor or implement tires. But if it must be applied to compacted middles, the compaction should first be broken with a tillage implement such as a high-residue cultivator.

4. If the price of ammonium nitrate is too high or it is not available, surface applications of urea and urea-containing fertilizers can be effectively used. *Do not broadcast these materials;* apply them in a narrow band next to the row. Unless a nitrogen-monitoring system will be used during the growing season, the nitrogen rate probably should be increased by 20–25 percent if the nitrogen source is 100 percent urea-nitrogen. The increase can be proportionally adjusted downward for materials that are not 100 percent urea. For price comparisons, make sure that you include the cost of additional material needed if rates are adjusted upward for a urea or urea-containing nitrogen source.

Starter Fertilizers

For years, the need for starter fertilizers (band applied close to the row at planting) has been widely debated. The reason for this debate is the extreme variability in response to these fertilizers in experimental studies. This variability is due to many factors, including residual soil-fertility levels, soil temperatures, planting dates, hybrid or variety used, and soil moisture.

The application of starter fertilizer almost always improves plant growth during the early or cooler growing season but does not always improve crop yield. It appears, however, that the odds of obtaining a yield response to starter fertilizer will increase rapidly as tillage operations decrease. The purpose of applying starter fertilizers is to adjust for the inability of a fertile soil to provide needed nutrients during the early growing season. The purpose should never be to replace sound fertilizer or soil-fertility management programs that are designed to maintain adequate levels of residual soil nutrients. In well-planned soil fertility and fertilizer programs, nutrients applied in starter fertilizers are a part of the total needed nutrient and are not additional nutrients.

The nutrient selection, rate, and application of starter fertilizers are probably more debatable than is the actual need for starter fertilizers. General recommendations should be made only for soils that are high in soil-test values for residual phosphorus and potassium. If residual levels are not high, the needs should be satisfied in applications that are separate from the starter application. Large amounts of fertilizer applied close to a germinating seed can be extremely toxic; because of this potential toxicity, starter fertilizer rates should be kept relatively low.

Some key points to remember when applying starter fertilizers are as follows:

1. If soils are high in residual phosphorus and potassium, nitrogen should be the key ingredient in starter fertilizers. However, phosphorus is sometimes needed.

2. In most situations, an ideal starter fertilizer rate is 20–30 lb/acre of nitrogen and 10–20 lb/acre of P_2O_5.

3. This ratio of 2 nitrogen to 1 P_2O_5 is just the opposite of the ratio in commonly available fertilizers. The 2:1 nitrogen-phosphorus ratio can be made easily at the farm by mixing solution fertilizers such as 10–34–0 with 32–0–0. Solid fertilizers with the 2:1 nitrogen-phosphorus ratio can be mixed by dealers with special blending or mixing equipment.

4. In some experimental studies, yield responses to potassium in starter fertilizers have been observed. Specific needs for potassium are difficult to identify. If crops are grown on soils in which responses to potassium have been noted even if soil potassium is high, then potassium should be included in the starter fertilizer. With most applicators, however, it is difficult to apply potassium in liquid fertilizer unless expensive sources of potassium fertilizer are used. Applying potassium with solid fertilizers is not a problem.

5. *Never* apply starter fertilizer in direct contact with seed or too close to the seed, even if exceptionally low rates are used. Some experimental studies have actually shown a yield response to low rates of fertilizer applied in direct contact with the seed, but the risk of severe seedling injury is too high to justify this practice.

6. The best application method depends on the equipment being used.

   a. If in-row subsoilers are used:

      (1) For solid fertilizer materials, let the fertilizers free-fall directly into the subsoil track from a tube mounted on the subsoil shank. The tube does not have to be below ground level.

      (2) For liquid fertilizers, mount tubes behind the shank that will deliver the fertilizer at least 3 inches below the seed. Liquid fertilizers tend to stop with first soil contact, so don't let these materials free-fall from a tube above the soil surface; they may stop too close to the seed.

   b. If in-row subsoilers are not used:

      (1) The best application is the old 2 X 2 method (2 inches below and 2 inches to the side of seed placement) if equipment can be modified for this application.

      (2) If the equipment cannot be modified, surface application directly on top of the row will provide beneficial results. Chances are high that only the nitrogen part of the fertilizer will be effective with surface applications, and the most economical approach would be to use a nitrogen-only fertilizer.

7. On soils and crops that respond to micronutrients and sulphur, benefits may be obtained by including these fertilizers in a starter mixture.

8. The likelihood of obtaining a positive yield response to starter fertilizer varies widely with soil types. In Alabama, crops grown on coastal-plain soil were found to be much more likely to respond to a starter fertilizer than were crops grown on soil in the Tennessee Valley. Although yield responses are generally not as frequent on Tennessee Valley soils as they are on coastal-plain soils, it is probably a wise decision to at least use a nitrogen starter regardless of the soil or planting date. The early-season growth advantage with starters can actually reduce weed-control costs. If the crop is higher than the weeds, postemergence directed applications are often possible with herbicides that are cheaper and more effective than the selective over-the-top herbicides.

Regardless of the tillage system used, well-planned management programs for lime, soil fertility, and fertilizer are essential for economical crop production. These programs should be based on soil testing and, in some situations, subsequent plant analyses. The basic difference between intensive conventional-till systems and a strict no-till system primarily centers around incorporated versus unincorporated fertilizers and lime. This difference requires that managers pay more attention to fertilizer-source selection, properties associated with the fertilizer, lime movement in the soil, and sampling depth.

9 Effects on Water Quality

J.M. Soileau and G.W. Langdale

Quality of Surface Water

The quality of surface water is generally enhanced with the introduction of no-tillage. This enhancement is primarily due to reduced sediment transport (Langdale and Leonard 1983, Langdale et al. 1983). Because of this reduction, highly absorbable cationic farm chemicals in sediment are not overland transported in significant quantities. After introduction of no-tillage, apparently the farm chemical that most enhances eutrophy (richness in nutrients) in surface-water bodies is soluble phosphorus (Langdale et al. 1985, McDowell and McGregor 1980a, 1980b). Although the total phosphorus mass in runoff is low, occasionally significant spikes of soluble ortho phosphorus (PO_4-P) may be found in runoff when surface-crop-residue cover is present. This PO_4-P increase occurs when runoff extracts PO_4-P from surface crop residues.

This enrichment may be reduced with tillage procedures that create more soil disturbance than does complete no-till, such as strip-tillage (in-row chisel used on subsoil) and paratilling. Another opportunity to use tillage that creates some disturbance occurs with the establishment of cool-season grain or cover crops (Langdale et al. 1990, 1992). These cool-season crops are established during September and October, months associated with very low erosion indices (Carreker et al. 1977, Mills et al. 1986). Herbicides used with tillage or cropping systems react according to their solubility, very similar to the way nutrients react (Smith et al. 1978, Leonard et al. 1979). The timing and precision of application (according to labels) of most pesticides are critical, to avoid surface-water pollution.

Surface-crop-residue management increases the amount and duration of soil cover, thereby decreasing the effect of raindrop energy and reducing the runoff of sediment and sediment-bound nitrogen, phosphorus, and pesticides, compared to results with conventional tillage. In the southeast, annual sediment losses from runoff considerably below the 5 ton/acre soil loss tolerance (T value) have been consistently reported with no-tillage soybean (McDowell and McGregor 1980a, 1980b), cotton (Yoo et al. 1989), corn (Langdale et al. 1985), and grain sorghum (Sharpely et al. 1991). However, the effects of crop residue management on nutrient runoff have not been as consistent. Although the concentrations of phosphorus and nitrate-nitrogen in solution are often higher in surface-crop-residue management than in conventional tillage (Sharpely et al. 1991, Soileau et al. 1994), no-tillage generally reduces the total transport of nitrogen and phosphorus in runoff because of the significant reduction in sediment-bound nutrients.

No-tillage or cover crops or both have been found to greatly reduce the amount of sediment, nitrogen, and phosphorus in runoff in most major land resource areas of the southeast, including the Coastal Plain, Piedmont (Langdale et al. 1979), and Mississippi Valley Silty Uplands (Shelton and Bradley 1987).

The effects of surface-crop-residue management on pesticide runoff and persistence in soils are not well known for most soil and cropping systems of the southeast. However, pesticides are subject to more rapid biodegradation in conservation systems because of higher organic-matter content near the soil surface. For the majority of commercial pesticides, regardless of tillage, the total runoff losses are less than 1 percent of the amounts applied, unless large runoff volumes occur because of high-intensity rainstorms shortly after application (Wauchope 1978, Willis et al. 1975). Exceptions are the organochlorine insecticides and the surface-applied wettable-powder formulations of herbicides, which may lose considerably more volume in runoff. Herbicides such as atrazine and cyanazine are lost primarily through the solution phase of runoff, and paraquat losses are associated primarily with sediment (Leonard et al. 1979). To minimize pesticide runoff, it is important to follow the application dosage and precautions stated on container labels and in regulatory guidelines.

Quality of Groundwater

A 1992 survey by the U.S. Environmental Protection Agency indicated that 10 percent of the nation's municipal water system and 4 percent of the rural domestic wells had detectable residues of at least one pesticide, but that less than 1 percent of all wells exceeded established Maximum Contaminant Levels (U.S. Environmental Protection Agency 1992). Nevertheless, it is important to adopt best management practices that minimize nitrate and other chemical leaching below the crop rooting zone to prevent potential contaminants from reaching underground aquifers.

The effects of surface-crop-residue management on groundwater quality need further study. A problem with relating residue management to the nitrate-nitrogen and pesticide concentrations in drinking water sampled from underground aquifers is that these aquifers are usually subsurface flow from a largely undefined extent of hydrological area, land use, ground cover, and possible nitrogen and pesticide sources. However, groundwater monitoring of soil percolate collected in lysimeters or drainage tiles just below the crop rooting zone has provided inferences as to the effects of site-specific soil surface treatments on the overall quality of groundwater. The average annual water surplus (rainfall exceeding evapotranspiration requirements plus water that can be held by the soil) has been estimated to range from 3 inches in parts of eastern Texas, to 20 or more inches for the rest of the southeast (Nelson and Uhland 1955).

One of the most successful strategies for minimizing the leaching of nitrate below the crop rooting zone and into groundwater is to grow cover crops during the seasons of normally excess rainfall (late fall through early spring in the southeast). As shown by lysimeter research and EPIC model simulation, nonlegume cover crops (such as cereal rye, wheat, barley, and annual ryegrass) are much more effective than legumes (hairy vetch and clovers) in taking up soil nitrogen and reducing nitrate leaching losses (Meisinger et al. 1991).

Although the abundance of macropores in no-till systems favors more preferential flow and water percolation than in conventional tillage (Tyler and Thomas 1979), later studies indicated less nitrate leaching with no-till cotton in Tennessee and with no-till corn in Tennessee and Kentucky than with similar crops planted after chisel plowing (Tyler et al. 1992). Another study at the North Appalachian Experiment Watershed at Coshocton, OH, strongly complemented these results (Edwards et al. 1992). These authors reported that earthworm burrows in no-till soil do not sustain homogenous flow. They also saw a reduced chemical concentration in percolate through macropores following the initial rainfall events after chemical application.

The amounts of nitrate and pesticides that leach below the root zone and eventually reach underground aquifers depend on many factors of climate, soil, land management, topography, and geohydrology. Site-specific factors that must be considered both within and between major land resource areas of the southeast include the chemicals used and application practices, amounts and intensity of rainfall, ground cover, soil texture, permeability, organic matter, internal drainage, slope, and depth of water table. Additional research is needed to evaluate the specific roles of various residue and crop management systems in striving to improve the chemical quality of surface water and groundwater.

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10 Compaction, Soil Strength, and Conservation Equipment

C.E. Hood

Compaction

Soil compaction comes about as aggregates are crushed, mainly from pressure on the soil from wheel traffic and conventional tillage tools. This compaction results in reduced pore space, which in turn leads to slower water penetration, poor drainage, and poorly aerated soils (Elanco Products Company 1992). Substantial losses of farm income due to machinery compaction have been correlated with tractor size, frequency of machinery use, weather conditions, and crops produced (Lavoie et al. 1991).

Soil Strength

Soil strength—a soil's resistance to penetration and displacement—increases with compaction. As soil strength increases, the tillage machines and no-till seeding and opening devices require greater force to penetrate and displace the soil. The results are increased wear on the soil-engaging elements and increased tractor-energy requirements. In sandy Ultisols of the southeastern Coastal Plains, the soil strength after surface-crop-residue management practices is more uniform than that after conventional tillage. Initially the more uniform soil strength may be attributed to reduced traffic, but in the long term, crop residues and reduced tillage are possible causes. Areas of high strength can inhibit root growth (Buscher and Sojka 1987).

Conservation Equipment

To reduce soil erosion for conservation compliance requirements, basic tillage tools need to be selected and operated carefully in order to retain the percent surface cover required in the conservation plan. However, with soybean residue, typical tillage tools such as the disk harrow and chisel plow (used separately or together) may not leave the required residue cover (Brown et al. 1992). On the market are new tools that use a residue-cutting coulter followed by a sharp shank that slices the soil surface and has blades that operate under the surface to break up compacted layers, with minimum disturbance of crop residue. Examples of such units are the Tye Paratill, DMI Yield-Till, Blu-Jet Sub-Tiller, and Yetter Zone Eliminator. The performance of deep-tillage tools to break up compaction zones should be measured to determine proper shank depth and spacing.

Rapid advances in no-till planters and drilling systems have occurred in recent years. Much of this technology applies to the southeast region. For monocrop applications, no-till planters with coulters ahead of the planting units are successfully seeding major crops such as corn, soybeans, and cotton into a previous row-crop stubble or residue. Typically for Coastal Plain soils, a subsoil shank is used between the coulter and planter to break up soil compaction. Rotating brush, finger, and disk devices that shift the residue away from the path of the planter have been introduced on the market in recent years.

No-till coulters are typically spring-loaded and typically require 250–350 lb each of down-pressure to function properly. The coulters function to provide cutting of the residue and also "fluffing" or tilling of a very narrow slot ahead of the planter opener. General classifications of coulters are ripple, bubble-fluted, and wavy, and all coulters are 16–18 inches in diameter.

The selection of coulters is based on type and amount of crop residue, soil strength, and width of till desired. Equipment dealers with experience in conservation planting and drilling systems for the local conditions can assist growers in selecting a coulter.

The use of no-till drill systems is accelerating as farmers look for ways to meet conservation compliance regulations. A wide variety of drill combinations and sizes are available on the market in widths of 8–20 ft (Elanco Products Company 1992). Two basic types of no-till drill systems are used: Coulters in combination with double-disk openers and press wheels are available in the coulter-cart arrangement coupled with a conventional grain drill, or the coulters may be integrally mounted on a frame with opener-press wheel units.

Double cropping with soybeans followed by winter wheat is a significant production practice in the southeast. Cotton following wheat has begun to increase in acreage. Burning the straw residue before planting the summer annual is a conservationally undesirable practice used by some farmers because their planting and drilling equipment will not function properly in the wheat-straw residue exiting the combine. Generally this is a failure of coulters to penetrate the soil surface due to heavy wheat-straw residue plus compaction in the field because of random traffic during production of the wheat crop. Combines without efficient straw "chopper-spreaders" intensify this problem. But several procedures can be adapted to minimize this problem, as follows:

1. Use an efficient combine straw chopper in proper adjustment.

2. Adjust the combine cutter-bar to leave as much wheat stubble standing as possible.

3. Avoid unnecessary stopping of forward motion of the combine, to minimize piles of straw at stopping points.

4. When chicken litter is used as fertilizer for wheat, take particular care to spread moderate amounts of litter uniformly, because heavy application results in lodging of the crop, which causes combining problems that result in points of excessive straw accumulation.

5. To reduce soil compaction, try to follow the same wheel traffic patterns in all operations in producing both crops. Optimally this means that the same wheel spacing is used on tractors and combine, and that the width of all planting equipment conforms to the combine-header width.

6. Minimize soil compaction areas where grain is off-loaded from the combine to trucks or other hauling methods.

Another recent development for double cropping in the southeast involves interseeding or relay intercropping of soybeans into standing wheat (Hood et al. 1991, Khalilian et al. 1991). (Because this is a new procedure, the technique will be demonstrated each May at Clemson University's Experiment Station at Blackville, SC.) With the use of an annual controlled-traffic production scheme for all operations (including harvesting), interseeded soybeans consistently yielded more than did conventionally double-cropped soybeans, with no adverse effect on wheat yields from the use of wider-spaced wheat rows. With a single deep tillage in the fall, soil cone index values in the row production zones, measured at 2 and 8 mo after tillage, did not change significantly over this period. Special curtains were provided on the rear of the combine to confine the wheat-straw residue to the traffic lanes, to provide additional mulching for weed and erosion control.

New-technology stripper headers mounted on conventional combines are gaining in popularity in the southeast for harvesting wheat that is being double cropped with soybeans (Successful Farming 1991). The units ingest only 10–25 percent of the straw while traveling about 1.5 times the normal combine speed. With most of the straw left standing intact, no-till drills and herbicides function well, providing improved soybean stands and weed control.

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11 Weed Management

A.D. Worsham

The major factor that delayed no-tillage in becoming a reality was the lack of methods to control weeds without tillage (Wiese 1985). And limited weed-control technology continued to deter the adoption of no-till crop-production practices even after they were possible. The continued development of new herbicides and cultivators designed to leave plant residues on the soil surface has now made weed management in no-tillage systems more effective and economical. This weed management, however, requires a higher level of management skills in growers (Triplett and Worsham 1986). Weed management problems remain in some crops of the southeast region, such as tobacco and vegetables. The control of some perennial weeds is still difficult in all crops.

In the early days of no-tillage, some nonfarm groups opposed it, claiming that more pesticides would be needed (Witt 1990). We now know that this is not generally true. In fact, the use of herbicides—especially preemergence herbicides—may be reduced in some crops by planting no-till crops in good cover-crop mulches (Worsham 1991, Bull et al. 1993). This will improve the environmental quality by reducing soil erosion, protecting surface water and groundwater from nutrient and pesticide pollution, and allowing increased use of postemergence herbicides. Postemergence herbicides have shorter half-lives, are more strongly adsorbed to minerals, and are thus less likely than preemergence herbicides to pollute groundwater and surface water.

Management Tactics

In most no-till cropping systems, a mixture of a "burndown" herbicide plus one or more residual herbicides is normally used. The burndown herbicide kills emerged grass and broadleaf weeds and any cover crop present at or before planting. Residual herbicides are normally applied before or at planting to control weeds germinating from seed. To complete the weed management program, one or more postemergence herbicides is usually needed for the additional control of broadleaf weeds or grasses or both. In some crops, postemergence herbicides can be substituted for residual herbicides.

Other traditional weed management tools—rotations, crop competition, and seedbed preparation—are still applicable in no-till. Tillage is part of other conservation systems and even of no-till in emergency situations.

Rotations

Crop rotation plays an important role in no-till systems. Certain weeds are easier or more economical to control in one crop than in another. For example, in corn or grain sorghum it is possible to control weeds that are more difficult and more expensive to control in soybeans. Cocklebur, annual morning-glories, and Pennsylvania smartweed can be controlled in corn in the preemergence, early postemergence, or last cultivation stages with the use of different herbicides for less cost than in soybeans or cotton.

For economical control of these weeds in soybeans, the timing of the application of postemergence herbicides is critical. Also, perennial weeds such as trumpet-creeper, horsenettle, and bigroot morning-glory can be controlled effectively in corn with 2,4–D or dicamba. They are very difficult to control in soybeans. Conversely, perennial grasses that are difficult to control economically in corn can be managed effectively and economically in broadleaf crops such as soybean and cotton.

The rotation of crops facilitates the rotation of herbicides that have different modes of action. This variance of action helps prevent the buildup of problem weeds, harmful soil residues, and herbicide-resistant weeds.

The cropping system may affect the choice of herbicide or the rate of its application. For example, if a winter small grain is to be fall-seeded after corn harvest, cyanazine in the tank-mix combination for broadleaf weed control would have less carryover potential than would atrazine or simazine. Many new soybean herbicides have restrictions on crop rotations. The user should read labels carefully to avoid problems in establishing cover crops or crops the next season.

Crop Competition

A competitive crop that can achieve early shading of weeds aids the overall weed management in no-till crops, especially double-cropped soybeans and late-planted grain sorghum. These later plantings should be in narrow rows, 20 inches or less apart, to provide quick closure of the crop canopy for the shading of weeds.

The user should follow the recommended crop-production practices to facilitate vigorous crop growth. This will establish a competitive edge for the crop in shading out weeds. Special care should be given to the planting rates and depth, because skips (missing plants) in the stand will result in greater weed problems.

Heavy mulch covers that have been left from cover crops also aid in weed control. Cover-crop mulches, especially small-grain, provide a physical barrier to weed emergence and also contain natural chemicals that leach out with rainfall into the soil below. These chemicals then suppress many large-seeded, difficult-to-control weeds in early season without affecting the deeper-planted crop seeds. In addition, the mulch provides shade that may suppress weeds, and the absence of tillage prevents some buried weed seeds from being brought near the surface, which is necessary for their germination. Dense small-grain or legume stands can also reduce the potential weed infestation and the weed size at planting time for double-cropped no-till soybeans or grain sorghum.

Cultivation and Seedbed Preparation

Certain weeds, such as johnsongrass, bermudagrass, and yellow and purple nutsedge, are difficult to control in a no-till system in some crops. In such cases, no-till planting may not be the best choice. However, certain preplant soil-incorporated herbicides can control these perennial weeds. Postemergence grass herbicides can now control johnsongrass and bermudagrass in no-till soybeans and cotton and also johnsongrass in no-till corn.

Usually fall tillage should be avoided on highly erodible cropland. Most winter cover crops can be successfully established without fall tillage by planting with a no-till drill into crop stubble.

If fields are fall tilled or planted with winter cover crops that provide rapid groundcover, then cutleaf evening-primrose, horseweed, whiteheath aster, and wild lettuce (all weeds that are difficult to control with burndown herbicides) are usually not a problem. Perennial weeds such as trumpet-creeper, redvine, bermudagrass, horsenettle, and briars are often more prevalent in fields that are not tilled in the fall. Additional herbicides may be required to provide acceptable control of these weeds in no-till systems. For many perennial weeds, treatment with herbicides in the fall before no-till planting is recommended. Glyphosate, dicamba, or 2,4–D plus dicamba can be used, depending on weeds present.

Herbicides

A herbicide program for no-till crops normally consists of a burndown herbicide for the control of existing vegetation plus one or more surface-applied residual herbicides for the control of germinating weeds, or postemergence herbicides for control of later emerging weeds, or both. Growers should consult publications from their respective states for specific recommendations of herbicides and rates (Lewis et al. 1989).

Controlling Problem Weeds

Control of Existing Vegetation

Crabgrass, fall panicum and lambsquarters over 3 inches tall, wild lettuce, and large plants of some weeds such as Pennsylvania smartweed, common and giant ragweed, common lambsquarters, and horseweed are more effectively controlled with glyphosate than with paraquat. Legumes (for example, alfalfa, clover, and vetch), annual ryegrass, goldenrod, pokeweed, and cutleaf evening-primrose are difficult to control with either of those nonselective herbicides. An approach to the control of these plants in corn is to use dicamba at 1/2 pint/acre at 7–10 days before applying paraquat or glyphosate, or to apply the dicamba over the top of 4- to 6-inch corn. For broadleaf crops, the addition of labeled preemergence herbicides to the burndown herbicide helps with these hard-to-kill weeds and cover crops.

Several studies have shown that weeds and winter cover crops should be terminated with herbicides 2–3 wk ahead of planting to eliminate problems with cutworms. Cutworm damage is one of the most common reasons for poor stands in no-till systems, but often the problem is not recognized because this pest is difficult to find in heavy residues. Furthermore, serious stand damage may occur before the crop emerges above the surface residue. Cutworm problems are usually more severe after legume cover crops than after small grains such as wheat or rye. The early termination of weeds and cover crops is also useful in conserving soil moisture for the rapid germination and emergence of crops.

Control of Problem Weeds After Planting

Yellow nutsedge. If fields are severely infested with nutsedge, no-till planting is not suggested. However, light infestations of yellow nutsedge in corn can be controlled with metolachlor preemergence at a minimum rate of 2 pints/acre. Atrazine and simazine may also be tank-mixed with metolachlor for additional control of broadleaf weeds. If nutsedge has emerged at the time of planting, use glyphosate in the tank mixture. If a preemergence treatment of metolachlor was not used, bentazon may be used postemergence for treating infested spots of yellow nutsedge within a field. It will take two applications at a 7- to 10-day interval to do the job. Treat only the infested areas to reduce costs. Linuron applied with the last cultivation is the only control method for purple nutsedge in no-till corn.

In soybeans, yellow nutsedge can be controlled with postemergence applications of bentazon, chlorimuron, or imazethapyr. In limited tests, imazethapyr applied postemergence has given acceptable control of purple nutsedge. Weeds that are still difficult to control in no-till cotton and soybeans are sicklepod, Texas panicum, Florida beggarweed, climbing milkweed, maypop passion-flower, broadleaf signalgrass, Palmer amaranth, annual morning-glories, cocklebur, and prickly sida.

Johnsongrass. In corn, postemergence applications of nicosulfuron or primisulfuron are excellent control measures. For soybeans, imazethapyr, quizalofop-P-ethyl, fluazifop-P, sethoxydim, fenoxaprop-P-ethyl, or clethodim give good control. The same herbicides except imazethapyr can be used in cotton. A repeat application is needed for some products.

Bermudagrass. Since there are no postemergence herbicides effective on bermudagrass in corn, treatment with glyphosate the previous fall is best. In soybeans, quizalofop-P-ethyl, fluazifop-P, sethoxydim, or clethodim are effective. The same herbicides except fenoxaprop-P-ethyl can be used in cotton. Repeat application is needed for some products.

Winter Annual Weeds as a Cover Crop

Cropland left idle after harvest in the fall often has over 50 percent ground cover of winter annual weeds during spring in the southeast region. A 4-yr study conducted in Mississippi reported an average 1.4 tons dry weight/acre of winter weeds in spring following a cotton crop, while wheat produced 1.7 tons/acre and vetch 2.0 tons (Hurst 1992). In a 3-yr study in Louisiana, native winter vegetation provided only 317–381 lb of dry matter per acre, although good ground cover was obtained by midwinter. Winter wheat and hairy vetch cover crops produced about 1 ton and 0.55 tons, respectively, of dry matter per acre. It was concluded that only no-till planting into a wheat or vetch crop reduced erosion rates to acceptable levels on highly erodible fields (Hutchinson et al. 1991).

Winter annual weeds providing cover are usually succulent mixtures of henbit, common and mouse-ear chickweed, and also various winter cresses and speedwells. Although these weeds provide ground cover while they are alive, after desiccating (drying), they do not persist long enough to provide significant erosion control and soil moisture conservation. Therefore, usually winter annual weeds are only slightly better than no cover at all during spring months, when planting and associated tilling are often followed by erosive precipitation.

Exceptions may be little barley, annual ryegrass, or volunteer wheat, which provide more mulch. It is best to plant a winter cover of a small grain or legume. Also, if no cover crop is planted, then troublesome, difficult-to-control annuals, biennials, and perennial weeds usually grow along with the smaller winter annual weeds. These may include dock, mustards, evening-primrose, horseweed, and wild lettuce. Without a planted cover crop, early-germinating summer annual weeds can emerge before the summer crop is planted. Many winter annual small grains (especially rye) and winter annual legumes (especially subterranean clover) suppress these early summer annual weeds (especially broadleaf weeds) by means of allelopathy (release of toxic substances by the plant).

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Generic names and trade names of pesticides used in the southeast

Generic name	Trade name
Atrazine	Aatrex
Bentazon	Basagran
Chlorimuron	Classic
Clethodim	Select
Cyanazine	Bladex
Dicamba	Banvel
Fenoxaprop-P-ethyl	Bugle
Fluazifop-P	Fusilade 2000
Glyphosate	Accord, Militia, Polado L, Ranger, Rodeo, Roundup, Shackle
Imazethapyr	Pursuit
Linuron	Lorox
Metolachlor	Dual, Medal, Pennant
Nicosulfuron	Accent
Paraquat	Cyclone, Gramoxone Extra
Primisulfuron	Beacon
Quizalofop-P-ethyl	Assure II
Sethoxydim	Poast, Poast Plus
Simazine	Princep
2,4-D	2,4-D, Weedone, Weed-B-Gon, Weed-Rhap

12 Insect Pest Management in Crop-Residue Management Systems

J.N. All

Insect pest management (IPM) is an important consideration for the production of field crops in management systems where residues are left on the soil surface. Entomological research conducted over the past decade has centered on characterizing the insect hazard in no-till systems (All and Musick 1986, Stinner and House 1990, Burton and Burd 1992). Studies have shown that in no-till environments, insect populations can react differently from their normal behavior in surface tillage systems. Also, insect pest complexes and residue-management systems vary in different locations of the United States, so the development of IPM programs for no-till should have a regional emphasis. For example, certain insects such as the southern corn billbug, *Sphenophorus callosus* (Oliver), appear to be stimulated and produce greater damage in surface-residue-management corn versus surface tillage corn, whereas infestations of the lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller), are controlled in corn systems with high surface residues.

A no-till environment can have a positive, negative, or neutral effect on pest-, crop-, and biological-control interactions, and knowledge of each effect is important in making IPM decisions (All 1989). In general, insects that are classified as resident pests (species usually not highly mobile and tending to increase populations year after year in a field) are more likely to produce increased problems in no-till environments, compared with those categorized as transient pests (species often highly mobile and initiating sporadic infestations). Previous crop history can be an important predisposing factor for increased pest hazard from resident-type pests in no-till crops.

When developing IPM strategies for surface-residue management systems, it is important to specify the type of tillage practice and to be aware that concomitant cropping practices (such as planting date, cover crop, and use of subsoiling) can greatly influence the risk of pest infestations irrespective of the type of tillage (All 1987). Generally, the highest risk of increased problems in no-till crops is in the first 30 days of plant growth.

The biological control of pests in no-till differs from that in surface tillage systems, and it is apparent that certain reduced-till environments enhance certain predators, parasitoids, and pathogens of pests. Most research indicates that in reduced-till, improvements in biological control occur during the seedling stages of crop growth (during the 45 days after germination) and that the regulation of pests in later crop-growth phases is similar to that in conventional tillage.

Preventive Control

Future IPM philosophy for most no-till systems will stress preventive control, which is a management-based rather than capital-based ideology for managing pests. Preventive control is the planned manipulation of cropping practices to produce crop environments that are either inhibitory (referred to as cultural control) or nonpromotive to pest population potential. Preventive control includes adjustments of cultural practices to (1) stimulate maximum crop resistance to or tolerance of insect injury and (2) enhance the involvement of predators, parasitoids, and pathogens in the biological control of pests. Since preventive control practices involve normal agricultural practices that are cost effective for crop production, their use for IPM involves minimal financial risk (All 1989).

Suppressive Control

Suppressive control is the use of measures, such as insecticides, that are designed to rapidly suppress insect outbreaks at a cost to the user (All 1989). The accurate monitoring of pests and the assessment of action thresholds* are necessary for cost-efficient implementation of suppressive control. Pest managers have generally found that the surveillance methodology developed for surface tillage systems is applicable to no-till. In the future, more-cost-efficient procedures for sampling pests, pest complexes, and key biological control agents need to be developed, along with the monitoring of key abiotic factors (such as temperature, rainfall, and humidity) that influence pest hazard. Then simplified sets of recommended actions can be devised for farmers, specifying when the use of insecticides is necessary.

Future Trends

All and Musick (1986) discussed insecticide technologies for pests in no-till systems and concluded that the chemicals and application methodologies available could be used effectively. Trends indicate that insecticide options will be reduced for farmers in the coming decades. Many pesticides are becoming restricted or eliminated from manufacture by the current registration and pesticide assessment policies of the U.S. Environmental Protection Agency.

Expenses in using conventional insecticides are escalating, due to the higher costs of pesticides and equipment and the increased expense associated with compliance with safety regulations. It is likely that many insecticides will be available on a prescription basis for application by only certified professionals, and this will increase the costs of chemical control. With fewer insecticide choices and unfavorable cost-benefit relationships for chemical control in crop-residue management systems, pest-control specialists will probably emphasize preventive control methods in future IPM programs. Cultivar selection, habitat management, and biological control will be used more than in previous years, and these preventive methods will require greater knowledge and commitment than did the chemical-based methods of the past. Thus, IPM research must advance from the descriptive phase of identifying insect hazard in no-till systems to the implementation phase of using IPM technologies that are cost efficient and user friendly.

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*Point at which unchecked insect populations will cause a loss of crop value greater than the cost of insecticidal control of the insect

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13 Plant Disease Management in Crop-Residue Management Systems

C.S. Rothrock

Farmers' rapid adoption of management practices that keep residues on the surface has caused plant pathologists to reexamine the importance of tillage and residue management in disease development. Disease incidence, the number of diseased plants, and disease severity are determined by the presence of a susceptible host, the presence of a virulent pathogen, and environmental conditions conducive for disease development. Surface-residue management can influence disease by (1) providing food and protection for pathogen survival and reproduction, (2) affecting the physical environment of the host and pathogen, and (3) influencing other soil and residue microflora that affect both the pathogen and host (Cook et al. 1978). In addition, surface managed crop residue may increase the weed hosts or alter the pathogen's distribution. Often changes in tillage practices will alter other cultural practices for a crop, and these other practices may also influence disease.

Crop residue management can increase, decrease, or not influence plant diseases (Cook et al. 1978, Rothrock 1992, Sumner et al. 1981). Tillage operations often have the greatest influence on pathogens that survive in host residue and spread over relatively short distances. Burying crop residue with deep tillage reduces a number of foliar diseases. The survival of foliar pathogens often depends on their association with host residues, and the rate of residue decomposition is slower for residue left on the soil surface than for buried residue. In addition, when host residue is left on the soil surface, these pathogens are near emerging host plants; this proximity favors infection.

Many soilborne pathogens that infect belowground plant parts have resistant survival propagules (sclerotia or spores such as chlamydospores or oospores), which enable these pathogens to survive after the host residue has decomposed. Clean tillage may move these fungi from the soil surface to deeper soil layers and thus reduce disease, as with a number of diseases caused by *Rhizoctonia solani*. However, in a study in Georgia (Rothrock 1987), root disease take-all on deep-tillage wheat was greater than that on no-till wheat, because deep tillage had spread the pathogenic inoculum to areas not diseased the previous growing season. Also, sorghum stalk rot (caused by *Fusarium moniliforme*) on no-till sorghum was less than that on deep-tillage sorghum (Doupnik and Boosalis 1980). Surface-residue management may also reduce some plant-parasitic nematodes, including soybean cyst nematode, *Heterodera glycines* (Tyler et al. 1983).

Surface-crop-residue management may increase or decrease volunteer crops that can act as hosts for pathogens and insect vectors of pathogens. These volunteer hosts may increase plant infection early in the growing season, resulting in greater severity of disease later in the growing season. Alternate hosts may also limit the effectiveness of crop rotation by maintaining high levels of pathogenic inoculum even though the host crop residue has decomposed.

The adoption of surface-crop-residue management systems influences a number of soil environmental factors. Increased soil water under these systems can reduce stress-related diseases, such as sorghum stalk rot, by reducing plant water stress (Doupnik et al. 1975). However, adverse soil physical factors associated with no-till may also increase the disease incidence. High soil-water content can predispose the host to infection and to disease development and can increase the disease incidence through increased motility of the pathogen or diffusion of host exudates.

Disease-Control Strategies for Conservation-Tillage Systems

Sound crop-residue management practices should be used in no-till systems as with other farming systems. The control of plant diseases under no-till uses disease-control strategies that are currently used by growers. As with any crop management system, growers need to be aware of disease prevalence and risk in their regions and individual fields. Fields should be scouted during the growing season for the presence and severity of various diseases.

Crop Rotation

The previous cropping history has a large impact on disease risk for the subsequent crop. The effectiveness of crop rotation varies with the disease. Diseases that rely on in-field or local inoculum and also pathogens that have a limited host range are most effectively controlled with crop rotations. Crop rotation allows the decomposition of old host residue, reducing the pathogenic inoculum and thus the risk of disease. Crop rotation is less effective for pathogens that can spread over large distances, have a wide host range, or survive for years as dormant propagules. Crop rotation is most effective when rotation is between widely differing crop species, such as corn and soybeans. For crop rotation to be fully effective, any weed hosts and volunteer crop plants need to be controlled, because they may carry over plant pathogens in the absence of the crop.

Resistance to Disease

Use of resistant cultivars is one of the most effective and inexpensive methods of disease control. Resistance is available to many of the aboveground diseases that often occur with conservation tillage. The importance of the use of resistant cultivars under no-till is demonstrated by research on southern stem canker in soybean, a disease that favors no-till (Rothrock et al. 1988). It was found that a soybean cultivar moderately resistant to stem canker gave similar yields in no-till and in clean tillage under heavy disease pressure.

Other Cultural Practices

Some cultural practices may influence plant disease and may be manipulated to favor the crops in residue management systems. The understanding of soil physical and chemical changes under no-till (including soil temperature, moisture, bulk density, and nutrient distribution and quantity) is important in limiting pathogen activity, limiting disease damage, and promoting good crop growth. The planting date may have to be changed to the time when soil temperatures and water content are most favorable for plant growth. The quantities or placement of fertilizer may have to be altered to maintain vigorous plant growth. The spacing of plants and rows may have to be adjusted for changes in plant growth and structure.

In all tillage systems, fungicides may be required in the management of disease. Often the fungicidal treatment of seeds is a good investment. Fungicidal treatment will provide a payoff if a pathogen is present in an environment that is conducive to disease development.

Recommendations

The adoption of no-till does not necessarily increase the risk of disease, but certain management strategies may reduce that risk. These strategies include the following:

- Rotation of crops to limit the buildup of pathogens.
- Planting of resistant cultivars when available.
- Adjustment of other management practices for the surface-crop-residue management system, including weed control, planting date, and fertilizer rates and placement to favor crop growth.

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14 Winter Cover Crops

D.W. Reeves, D.D. Tyler, and W.L. Hargrove

Maintaining vegetative soil cover by means of winter cover crops is important in the southeast, and the adaptability of such cover crops is greater there than in other regions. Research has consistently shown the benefits of cover crops in dramatically reducing water erosion and in improving the productivity of eroded soils (Bruce et al. 1987, Langdale et al. 1991). When cover crops are included in surface-crop-residue management systems in the southeast, soil losses decrease from over 5 ton/acre/yr to about 0.1 ton. Winter cover crops complement the use of no-till techniques, especially in crops like cotton or in silage-producing systems that do not leave significant amounts of residue following harvest. Cover crops and no-till systems can reduce the transport of nitrogen and phosphorus in runoff to surface waters (Sharpley and Smith 1991). Where nitrate leaching to groundwater is a potential problem, cover crops offer an effective means of reducing the amount of nitrogen leached (Meisinger et al. 1991).

Improving Soil Physical Properties

Cover crops improve the soil physical properties, primarily due to the production of biomass, which serves as a source of soil organic matter and substrate for beneficial soil biological activity (Bruce et al. 1991). But the benefits of cover crops in maintaining or increasing soil carbon and nitrogen can be negated by tillage. The most important agronomic factor that is affected is soil water. Infiltration is increased by cover crops because their residue dissipates rainfall energy, causes changes in soil aggregation, and promotes formation of macropores by roots. Legume cover crops are especially effective in improving soil physical properties. In the Georgia Piedmont, grain sorghum grown no-till behind a crimson-clover cover crop resulted in 89 percent water-stable aggregates compared to 58 percent water-stable aggregates with conventional tillage and no cover crop (Bruce et al. 1991). After 4 or 5 yr, the no-till grain-sorghum/crimson-clover system increased the simulated rainfall infiltration by 100 percent compared to that under conventional-till soybean or grain sorghum (Bruce et al. 1992). The combination of cover crops and no-till also increases the bearing capacity of soils and reduces the compacting effects of equipment traffic (Reeves et al. 1992).

Requirements of a Cover Crop

In crop-residue management systems, a cover crop must meet certain requirements. It should be easy to establish, have a rapid growth rate so as to quickly provide ground coverage, produce a sufficient quantity of dry matter for the maintenance of residues, be disease resistant and not act as a host for diseases of the cash crop, either die back at the proper time or be easy to kill, and be economically viable.

Categories of Cover Crops

There are four general categories of cover crops: grasses or small grains, legumes, brassicas, and natural vegetation (winter weeds). As pointed out in chapter 11 (Weed Management), weed residue does not generally persist long enough to provide substantial benefits, compared to the benefits of planted cover crops.

Brassicas Versus Small-Grain Crops

Brassicas (radishes, turnips, canola, or rape) are not commonly used as cover crops in the southeast. They are as effective as small-grain cover crops in reducing nitrogen leaching but do not immobilize nitrogen as small grains do. This is because the carbon-to-nitrogen ratio of brassica residues is usually 20:1 or less, whereas that of small-grain residues is usually greater than 30:1. A carbon-to-nitrogen ratio of 20:1 is a "threshold" value. At ratios of less than 20:1, nitrogen is released from the residues to the soil, which is called nitrogen mineralization. Where ratios are greater than 20:1, substantial portions of nitrogen from manures, fertilizers, and soils are generally tied up by the microbes that decompose the residue, which is called nitrogen immobilization. Compared to small grains and legumes, brassica cover crops are harder to establish, are more susceptible to plant diseases, and do not adapt to as wide a variety of soils and climates.

Nitrogen Leaching

Small-grain or grass cover crops (oat, wheat, cereal rye, and annual ryegrass) are currently the choice for reducing nitrogen leaching. Rye is especially effective for this purpose because it establishes itself early, produces large amounts of biomass, and takes up large quantities of nitrogen. The nitrogen content of small-grain cover crop residues varies, but usually ranges from 25 to 50 lb/acre. However, this nitrogen is usually not readily available in the early stages of the following cash crop because the carbon-to-nitrogen ratio of grass cover crops is ordinarily greater than 30:1. Early killing of the cover crop results in a narrower carbon-to-nitrogen ratio in the residue, but the total residue is reduced and the residue decomposes more rapidly, thus reducing the soil coverage. The potential for short-term nitrogen losses by immobilization is frequently greater in no-till systems because some of the nitrogen is incorporated into the residual soil organic matter, which generally increases in no-till systems with cover crops (as discussed in ch. 16). This nitrogen immobilization, coupled with the wide carbon-to-nitrogen ratio of small-grain cover crops, means that a starter fertilizer to supply 25–30 lb/acre of nitrogen should be applied to crops planted no-till behind small-grain cover crops.

The nitrogen content of legume cover crops also varies, depending on the species, location, and kill date. Most of the research on winter annual legume cover crops has been conducted in the southeast region. The average nitrogen content of aboveground residues from legume cover crops reported from this research is 90–110 lb/acre. The carbon-to-nitrogen ratio of legume cover crop residue is almost always less than 20:1, which means that most of the nitrogen in the residue is rapidly mineralized and becomes available to succeeding crops. This is an advantage unless the purpose of the cover crop is to control nitrogen leaching or to build residual soil organic matter. In that case, a small-grain cover crop would be better. Research has shown, however, that nitrogen release from legume residues may be delayed beyond the time that the succeeding crop begins to need nitrogen. Therefore, for crops following legume cover crops in conservation-tillage systems, fertilizer nitrogen applications should be made at planting. It is not necessary to split nitrogen applications to no-till crops following legumes.

Disadvantages of Cover Crops

There are a number of potential disadvantages to using cover crops. Fortunately, proper management techniques will lessen the probability of a negative effect of cover crops, thus increasing their acceptance by growers. The primary reason that growers do not use cover crops is the cost of planting and then terminating the cover crop. Legume cover crops are more expensive than small-grain cover crops due to the cost of seed. The increased seed costs with legume cover crops are generally offset by the value of the nitrogen fertilizer equivalence from the legume (estimated at 50–90 lb/acre). The actual nitrogen fertilizer needed by the crop following the legume cover crop may or may not be reduced, because the yield potential (and the consequent nitrogen demand) of the crop following the legume cover crop may be increased.

Risks and Gains With Legume Cover Crops

The potential economic benefits with a legume cover crop are usually higher than those with no cover crop or a small-grain cover crop. But the potential risks with legumes are greater than those with small grains, due to legumes' increased susceptibility to diseases and winter kill. These risks can be reduced by choosing an adapted legume and by ensuring that the cover crop is planted as early as possible. The two most common winter legume cover crops in the southeast region are hairy vetch and crimson clover. Crimson clover is the legume of choice in the Coastal Plain and Southern Piedmont, and hairy vetch is better adapted in more northern areas. In areas where it is adapted, the advantage of crimson clover is that it is earlier in producing significant biomass and in setting seed.

Cropping Strategies

Economic risks can also be reduced by innovative cropping strategies. Grain sorghum can be planted late enough to allow crimson clover to reseed in a no-till system (Touchton et al. 1982). New tropically adapted corn hybrids can also be planted late enough that they allow crimson clover to reseed in a no-till system (Reeves 1992). Crimson clover planted in the fall followed by no-till soybean will allow the clover to reseed; corn can then be planted into the reseeded crimson-clover (and soybean) residue in spring of the second year, to take advantage of the nitrogen supplied by the legumes. When full-season corn is grown, this system requires planting of the cover crop every other year rather than annually (Oyer and Touchton 1990). Dual-use cover crops reduce the production costs. The common wheat/soybean double-cropping system takes advantage of wheat as a cover crop as well as a cash crop.

To reduce the risk of a cover crop depleting the soil water before planting of the cash crop, the cover crop should be killed 10–14 days before that planting. If a winter cover crop is used, the risk of a cover crop depleting the early-season soil water is about the same, whether the cash crop is grown with conventional-till or no-till. However, the potential for yield will increase following a cover crop as a result of increased infiltration, and the conservation of water later in the growing season is generally achieved when the cover-crop residues are left on the surface.

Limited research has also shown that the stand reductions of some crops, most notably cotton, following cover crops (especially legumes) can be reduced if the residue is not incorporated into the seed zone. Most problems associated with stand reductions in cover-crop residue are due to residue interference with planter operation, which results in poor seed-and-soil contact and incorrect depth of seed placement. Growers can now choose from many designs of planters to facilitate planting into heavy residue. The proper equipment and the proper setting of planter adjustments are critical to obtaining a good stand with crops like cotton, which are susceptible to stand reductions in no-till systems. In difficult situations, the rate of seeding may be increased.

Cover crops may play a major role in the conservation compliance regulations of the 1985 Farm Bill. With proper management, the use of cover crops can be environmentally and economically advantageous for growers.

Winter Annual Legumes in No-Till

The successful use of winter annual legumes in no-till cropping requires careful management. The following guidelines were developed in Tennessee to apply to most of the southern loess belt region (MLRA 134), and have been modified here for the entire southeast:

1. Selection of cover crop. It is essential for the species to have good seedling vigor for establishment in crop residue and for cold tolerance to survive mid-South winters. Thirteen legumes have been evaluated, and results are summarized as follows: (a) Ball clover, berseem clover, red clover, buttonclover, and common vetch are not suited for this management; (b) arrowleaf clover, subterranean clover, and Austrian winter pea are marginally adapted; and (c) bigflower vetch, hairy vetch, caley pea, and crimson clover are adapted.

2. Date of planting. The planting date affects the crop's establishment, canopy development, winter hardiness, accumulated growth, and amount of fixed nitrogen. Crimson clover should be planted by late September. Hairy vetch usually survives winters if planted by middle or late October; but if it is planted after late September, the degree of soil protection and the amount of growth and nitrogen accumulated in spring will be less.

3. Seeding rate. The recommended seeding rates for most legumes are based on conventional tillage and on use as forage crops; they include 20 lb/acre for crimson clover and 30 lb/acre for hairy vetch. Of course, seed costs are part of the total cost of using cover crops, and preliminary results indicate that recommended seeding rates may be reduced by 25–50 percent (with good planting management) without sacrificing any of the nitrogen-fixing benefits.

4. Planting methods. The topseeding of crimson clover and hairy vetch into crop residues *may* result in acceptable stands *if* conditions (planting date, soil, moisture, and weather) are suitable. But there are some methods of assuring good seed-and-soil contact, which reduces the risk of stand failure. Planting with a no-till drill is ideal, but light disking followed by planting with a grain drill (or even broadcasting) usually produces adequate stands.

5. Termination date. In no-till systems, which capitalize on the surface mulch provided by legume residue, cover crops should be sprayed with burndown herbicides 7–10 days before the target planting date, to allow soil warming and to facilitate planting into the residue. This is especially true with no-till cotton.

6. Termination method. Burndown herbicides (such as paraquat or glyphosate), which are recommended for weed control in no-till production, may be used to kill the

legumes. Tank-mixing of some residual herbicides may increase the effectiveness of burndown chemicals. Legumes may be killed by various tillage practices (such as chiseling or disking) on sites that are not subject to an erosion hazard.

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15 Management Options for Lands Concluding Their Tenure in the Conservation Reserve Program

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Most of the highly erodible lands contracted into the Conservation Reserve Program (CRP) suffered much erosion, organic-matter loss, and soil structural deterioration while they were in cultivated crop production. In the CRP, most of the land was returned to grass, and the structure and organic-matter level of the soil improved. If these improved lands are tilled again following the CRP, the organic-matter level and structure resulting from the period in grass will be rapidly lost.

A critical question for managers of post-CRP land returning to crop production is how to maintain the benefits derived from 10 yr of grass. Going directly into no-till can be a cost-effective method of doing this. No-till avoids the rapid biological oxidation of organic matter that results from moldboard plowing (Reicosky and Lindstrom 1993). No-till also maintains the pore geometry and continuity developed under grass. Macropores extending from the soil surface to deep within the root zone are maintained, resulting in high water-intake rates that reduce runoff and erosion. By keeping crop residue on the surface and keeping a few millimeters of highly organic soil near the surface, no-till also reduces evaporation. This combination of increased infiltration and decreased evaporation makes more water available for crop production and groundwater recharge. The additional groundwater increases the base flow into our streams from springs and seepage faces, and that base flow sustains the desirable components of our wetland ecosystems. No-till also reduces the populations of annual weeds that require soil disturbance for germination.

No-till production systems must be adapted to the conditions of the region and to the resources and needs of the producer. The purposes of tillage include the control of weeds, insects, and pathogens. When tillage is discontinued, alternative means of controlling these pests must be used. Herbicides provide cost-effective control for most weeds. Other ways of controlling pests are mowing field borders before weed seed set; using disease-free and fungicide-treated seeds; using crop rotations to break the life cycles of diseases, insects, and weeds; and narrowing the rows to allow earlier interception by the crop of the sunlight and nutrients that otherwise nurture the weeds. Other chapters in this publication discuss the development of successful no-till systems. The following discussion in this chapter focuses on CRP: how grass affects soil properties, the rates at which grass improves soil properties, post-CRP management options, the potential impacts of no-till after CRP, and some basic no-till guidelines.

Conservation Reserve Program (CRP)

The CRP was initiated in 1985 under the Food Security Act with the intention of placing up to 45 million acres of highly erodible farmland under protective cover. Public perceptions of the economic, social, and environmental state of farming before the initiation of the farm program influenced this multiyear land-retirement program. During this time, farm prices were low, large crop surpluses existed, farm foreclosures were increasing, and agricultural exports were decreasing. Lobbyists argued that these surpluses were preventing the improvement of grain prices and that due to these surpluses, large blocks of highly erodible land could be placed under protective unharvested grass cover. There was also public concern that current farming practices were destructive to both the soil's productive capacity and the wildlife habitat. Economists anticipated that the reduction in acres of grain would reduce grain production so that market prices would rise closer to target prices. Consequently, crop support prices would be lower per bushel and would be paid on fewer bushels. Based on these potentials for improving erosion control, farm prices, and the national budget, the CRP got under way.

Under this program, USDA pays CRP participants an annual rent for 10 yr, plus half the cost of establishing a conserving land cover. To be eligible for the program, land has to be potentially highly erodible, or actually eroding at an excessive level, or environmentally sensitive. A condition of this enrollment in CRP was that the farmers surrender their use of a proportional amount of their commodity crop base acreage. This subtracted base acreage is "returned" when the land is retired from CRP.

The objectives of CRP evolved during the program, and new procedures were developed for selecting lands from those proposed for the program. The new procedure used a productivity-based rental rate and ranked bids based on the ratio of the environmental benefits index to the Government cost of the contract. Special provisions for wetland enrollment were made during the eighth and ninth sign-up periods. U.S. conservation policy is moving to promote broader stewardship of all natural resources on the farm, as indicated by the addition of the Wetlands Reserve Program, the Agricultural Water Quality Incentives Program, and the Environmental Easement Program.

Status of CRP

By 1993, 36.4 million acres of highly erodible and environmentally sensitive land were enrolled in CRP. The first contracts will expire in October 1995. By October 1997, about 24 million of these acres will have been released. By 1993, commodity crop base acreage had been reduced by 23.3 million acres. One of the major payoffs of CRP has been its significant improvement of wildlife habitat. This benefit has brought a major portion of the environmental groups to support CRP and proposed related programs. The average erosion reduction on CRP lands is estimated to be 19 tons/acre/yr. Of the land that went into CRP, 2.4 million acres were planted with trees. This tree-covered acreage is in the southeast region, has a good start toward producing a harvestable timber crop, and will probably stay under tree cover for at least another 15 yr.

As contracts expire, producers are questioning what the future holds for grassland enrolled in the CRP. Many of the highly erodible lands accepted in the CRP had suffered much erosion and structural deterioration. The organic-matter contents and infiltration rates of soils in these lands have generally improved during their period in grass. However, these improvements will be rapidly lost during and immediately after tillage.

As CRP acres become eligible for release, landowners have many options, including leaving the acres in grass for hay or livestock production, or establishing wildlife or recreation enterprises. Another option available to contract holders is to return all or a portion of the land back into crop production. Surveys indicate that over half of CRP contract holders plan to return to cropping after contract expiration. Many of these producers lack experience in dealing with the grass and the large amounts of residue accumulated after the land has lain idle for 10 yr.

Effects of Grass on Soil Properties

The most important characteristics of soil structure are the size, distribution, and geometric arrangement of pores. These properties of soil pores determine the infiltration rates, internal drainage and aeration, water-holding capacity, and the portion of soil water that is available to plants. These characteristics tend to become optimized when there is sod cover. Soils with the best aggregation for crop growth in the United States are soils that have been in grass for many years. These soils have greater amounts of organic matter, structural stability, total pore space, air-filled pore space, higher hydraulic conductivity, and higher infiltration rates than do cropped soils that are conventionally tilled. Also, soils of long-term grasslands tend to have more pores in the size range that contributes to field water-holding capacity than do cropped soils.

All these characteristics result in improved water availability for plant growth. Earthworm channels connected to the soil surface reduce the runoff and improve infiltration into the root zone. Populations of earthworms have been observed to be six to nine times higher in established grasslands than in cultivated soils.

Soils in long-term grass also show improved mechanical properties that allow traffic and tillage under wetter conditions. Farmers of fine-textured soils, which are tilled following a long period in grass, observe that the time periods between when a soil is too wet to till and when it is too dry to till decrease each year after tillage begins. These farmers plan the timing of their tillage operations based on these observations.

Soil aggregates from North American virgin grasslands are more stable than those from cultivated lands. The differences appear to be due to a cultivation-induced loss of particulate organic matter that helps bind small aggregates into larger aggregates. Particulate organic matter consists primarily of partially decomposed residue and roots. This fraction has a higher turnover than do other forms of organic matter and requires continual input into the soil. Grasses that form a sod cover are an excellent source of leaf and stem residue and of organic matter associated with continual turnover of an abundant fine root system. The superior aggregation qualities of grasslands result from the ideal conditions of simultaneous formation and stabilization of macroaggregates found in the grass rhizosphere. The reduced returns of root-system organic matter to the soil and the rapid biological oxidation of organic matter induced by tillage appear to account for the lower organic carbon and nitrogen found to a depth of 18 inches in long-term cultivated soils compared to those in virgin grasslands (Bauer and Black 1981).

When grasslands are cultivated, organic carbon and nitrogen decline most rapidly during the first 10 yr of cultivation and then decline more gradually, depending on cropping system and climate (Bauer and Black 1981). The soil structure deteriorates even more rapidly, with the greatest rate of destruction occurring in the first 2–3 yr after cultivation of long-term grasslands. The effects of tillage on soil properties after cultivation depend to some extent on the soil type. However, all soil types examined (loamy sand to clay) exhibit degraded soil physical properties resulting from tillage. Long-term tillage in these soils resulted in reduced water availability and aeration within the root zone. Pores of the sizes that hold water at suctions where it is available to crops were reduced 14 percent by 12 yr of tillage on a Crowley soil in Arkansas (Scott and Wood 1989).

A major objective of the CRP is the protection and improvement of the soil surface with grass cover. The grass cover protects the soil surface from raindrop impact, traps water temporarily in surface microcatchments, and allows the development of cracks and pores that open up the surface, all of which reduce the runoff and associated erosion.

Soil Improvement From CRP (Long-Term Grass)

Soil structure improves when cropped land is put back into grass. This is accounted for by the "land use residual" attributed to grass rotations in the development of cropping factors in the Universal Soil Loss Equation. Improved soil properties after grass can result in increased yields. Significant improvement in soil structure has been observed in 3–5 yr. However, more time is required for the restoration of soil properties to the state found in the virgin soil. Mazurak and Ramig (1962) estimated that the effects of grass in a medium-textured soil in Nebraska reached its maximum benefit after 10–12 yr. Soil aggregate distribution, stability, air permeability, and hydraulic conductivity improved with time in the grass treatments. A review by Kay (1990) of the effects of grass on the improvement rate of soil-structure stability indicates that significant improvements will continue for at least 10 yr. Improvements are likely to continue after this time period but at a slower rate.

The management of grass influences the benefits of grasses on soil properties. Haying grassland slows the rate of change in soil structure (Mazurak and Ramig 1962). If a legume such as alfalfa is used in the grass mix, haying reduces most of the benefits of alfalfa to the soil nitrogen pool (Haas et al. 1976). Although haying slows the effects of alfalfa and grass on soil structure, improvement continues for at least 5 yr, as shown by the increased organic matter and aggregate stability.

The degree of soil improvement from 10 yr of grass is likely to depend on the soil and the site. As a general rule, the greater the amount of soil-structure deterioration from past cultural practices, the more likely that grass management will improve the agronomically important soil characteristics. Rasiah and Kay (1994) found that if soils had higher levels of organic matter and other stabilizing materials at the time of grass introduction, the time required for soil-structure regeneration was reduced. Soils in the CRP generally fit into the category of degraded soils whose organic matter is lower than that of surrounding soils, because they were primarily allowed into the program based on their "highly erodible" classification. Highly eroded soils tend to have reduced productivity, degraded soil structure, lower organic matter, and a less-than-ideal environment for root growth (Lindstrom et al. 1992). Soils that tend to be less stable and have less cohesion, such as sandy loams or compacted clay soils, may also benefit from the organic-matter inputs of 10 yr of grass. Soils with past deterioration or less-than-ideal physical characteristics are likely to be poorly buffered from tillage-induced changes and are most likely to rapidly lose the improvements derived from CRP when tilled. The surface of these less-than-ideal soils is also more likely to seal following tillage, which reduces the infiltration and increases the water runoff and soil erosion. A critical question for managers of post-CRP land returned to crop production is, How can the advantages gained from 10 yr of grass production be maintained or prolonged?

Although the degradation of structure of soils taken out of sod and tilled is well documented, less is known about the effects of no-till cropping on lands previously in sod. Presumably the rate of decline is not as great for soils in no-till, because the reduction of or abstinence from tillage reduces disturbance of the structure and reduces the rate of biological oxidation of the organic matter.

Post-CRP Options

If funding can be obtained, the best approach environmentally for highly erodible CRP lands is probably to extend the contracts. This will allow the soils in the program to continue to improve and will keep erosion under control. Another proposal is to subsidize a rotation program that involves 4 yr in grass production followed by 4 yr in grain production. Still another proposal is to lower the CRP payments to keep the lands in grass but to allow grazing or haying on these lands. The last proposal has met considerable opposition by farmers who have land already in hay production and who object to subsidized hay production that would compete unfairly with their product. The soundness of their arguments has been acknowledged by administrators and legislators. Consequently, it is unlikely that haying and grazing will be allowed on lands on which CRP payments are being made, except in emergencies.

Farmers who choose to use their post-CRP land for haying or grazing operations will have to pay their own way. In some parts of the country, such haying and grazing operations on these lands can be economically viable if current hay prices can be sustained. However, the demand for hay is declining as the consumption of red meat declines, so local hay markets are limited, transport costs of hay are high, and major increases in hay production may occur after CRP is over. The reduced demand and increased supply are likely to result in depressed prices and little profit for the farmer.

Another market that may develop for dry grass is its use as a fuel for power plants. Initial results from studies funded by the Department of Energy are encouraging, indicating that prices in the range of $40-$50/ton can be paid for dry hay used for this purpose. However, the construction of power plants and the development of this market will take at least 10 yr, so this market will not be available to many (if any) farmers when their land comes out of the CRP.

Before deciding what to do with their post-CRP land, individual farmers should evaluate the existing and developing markets in their area. Existing commodity support payments will help protect farmers from decreasing prices for their products on the supported crops for which they have base acreage allotments. However, the long-term provisions of GATT will reduce those supports.

Most CRP lands in trees have a good start toward production of wood for paper and lumber and will probably remain in trees until that harvest.

The following is a list of possible options for the farmers:

1. Maintain grass cover on the land.
    a. Produce hay. Use management designed to avoid disturbance of nesting birds (for example, delay the first cutting until danger of disrupting nesting birds is past).
    b. Graze animals on the land. Rotate grazing areas to minimize disruption of nesting birds and grass deterioration.
    c. Manage the land to preserve wildlife. This can include development of fee hunting preserves, etc., and may be combined with some of the other options where provision of improved wildlife habitat is designed as part of the conservation plan.
    d. Extend the CRP contract, if possible.
2. Return the land to cropping.
    a. Use no-till practices (low-disturbance systems). Plant into dead sod, and use appropriate rotation systems to manage weeds, pests, and fertility without a dramatic increase in purchased inputs. Maintain surface residue and soil structure.
    b. Use a wide V-blade sweep to undercut sod. Then use no-till or minimum-till methods of planting and crop production.
    c. Use a moldboard or chisel plow before a no-till system. After plowing disrupts and buries a major part of the initial residue, no-till will maintain the residue of subsequent crops on the surface.
    d. Use only conventional tillage. The tillage system and rotation must be modified to fit the conservation plan developed for conservation compliance, if the land has been designated as highly erodible.
    e. Create a meadow and rotate with crops. Plant grass, legumes, or a mixture of the two as a meadow. Rotate each field between crops and meadow to reduce the average annual erosion rates.

For most CRP lands where contracts cannot be renewed, no-till management appears to provide the greatest potential for achieving reasonable net returns while retaining most of the soil quality improvements achieved during CRP. The following section further describes how CRP lands can be cost-effectively transitioned to economically and environmentally sustainable production systems (see also ch. 7).

No-Till After CRP

Cropping practices that avoid tillage have the advantage of avoiding the rapid mineralization of carbon and nitrogen that occurs when grass or crop residues are mixed with the soil by tillage. Reicosky and Lindstrom (1993) measured successively higher rates of carbon dioxide from wheat stubble plots subjected to no-till, disking, chisel plowing, or moldboard plowing. They found that the biological oxidation or carbon loss during 19 days after moldboard plowing was greater than all the carbon contained in the stems, leaves chaff, and roots of the previous wheat crop. The oxidation rate of organic matter from the no-till area was about 15 percent of that from the moldboard-plowed area. Lamb et al. (1985) measured soil organic nitrogen losses in the top 12 inches of soil that had been in native grass and was then cropped to winter wheat for 12 yr in a wheat-fallow system. The nitrogen loss, expressed as a percent of nitrogen in the native grass soil, was 3 percent for no-till, 8 percent for stubble mulch, and 19 percent for plowed (black fallow).

The levels of organic carbon and nitrogen after 10 yr of no-till or conventionally tilled corn production in a Kentucky soil that had previously been in bluegrass sod were evaluated (Blevins et al. 1983). Approximately twice the carbon and nitrogen amounts were seen in the surface soil layer of no-till.

Following the development of improved structure during 10 yr of undisturbed grass, as the transition is made to cropping systems, it is obvious that leaving the soil intact in no-till management causes less immediate disruption of the improved structure than does conventional tillage. Chan and Mead (1989) measured water-transmitting macropores in a permanent pasture that had been lightly grazed. They found that cultivating to a depth of 4 inches for 4 yr completely disrupted the macropore structure and resulted in increased water runoff by reducing preferential flow within the macropore network and altering the pathway of infiltrated water movement. In contrast, the macropore system remained intact with no-till crop production.

In most cropping situations (no-till or conventional tillage) used after grass, the carbon input from root systems of the new crop will be less than that from the roots of the grass. Consequently, some loss of soil-structure stability over time should be expected. The exact extent to which no-till can prolong the benefits of grass sod has not yet been determined. However, no-till systems introduced to tilled fields significantly improve the soil surface characteristics when abundant residues are produced. This improvement is likely to lead to better infiltration and reduced erosion. The provision of optimum crop nutrients and the use of cover crops with no-till allow additional residue production and carbon input into the soil. A study in Kentucky (Ismail et al. 1994) found that the organic carbon content of a soil that had been degraded by tillage was restored to almost the same level as that of adjacent long-term bluegrass sod after 20 yr of cropping fertilized no-till corn with a rye winter cover crop.

Conversion from conventional-till to no-till management systems has increased the soil organic-matter content and improved the soil structure in soils having low organic matter and poor structure, but the structural improvements achieved during 3 yr of no-till can be eliminated with one moldboard plowing (Kladivko et al. 1986). These improvements in soil structure with no-till are not obtained immediately. As discussed in chapter 16, several years are often required before significant soil-structure improvements can be documented. Soil erosion from either wind or water is reduced with the onset of no-till management simply because crop residues on the soil surface protect the soil from erosive forces. Water runoff is generally reduced when the management is changed from conventional tillage to no-till, but not always.

CRP lands present many opportunities to initiate no-till in a situation where soil organic-matter contents, soil structure, and infiltration rates have already been improved.

In eastern South Dakota on land that had been in an alfalfa-bromegrass sod for 6 yr, Lindstrom et al. (1994) initiated moldboard plow, chisel plow, and no-till corn production systems and obtained similar yields from all systems. In the fourth year of production, immediately after planting, artificial rainfall was applied at a rate of 2.5 inches/hr for 1 hr on each of two consecutive days to each management system and on adjacent undisturbed alfalfa-bromegrass sod. No water runoff or soil loss occurred from the areas that were still in the sod or from the areas that had been in no-till corn production. An average of 49 percent of water applied to crops in the moldboard-plow tillage system and 34 percent of water applied to crops in the chisel-plow tillage systems was lost to runoff. Soil loss was 11.8 tons/acre from the moldboard-plow systems and 2.4 tons/acre from the chisel-plow systems.

In the northern Corn Belt, conversion to no-till management from conventional-tillage crop-production systems has in some cases resulted in at least temporary decreases in infiltration (Lindstrom et al. 1981, Mueller et al. 1984). However, no-till row-crop production systems following sod (Lindstrom et al. 1994) sustained much higher rates of infiltration than did the tilled systems following sod. The improvement in organic matter, soil structure, and infiltration that occurred under the 6-yr brome-alfalfa growth was maintained with no-till into the fourth cropping season, with no indication of soil degradation with the continued no-till cropping. The no-till system sustained and promoted soil macropores that extended from the surface to deep within the root zone and that were open to the atmosphere and protected by residue cover. These macropores resulted in high infiltration rates, reduced runoff, and subsequently reduced soil loss.

In the early 1970's, innovative farmers in the southern hill country used paraquat and atrazine to kill fescue grass and also used newly available no-till planters that cut through sod with fluted coulters to plant corn without tillage. The resulting yields in some cases exceeded 200 bushel/acre (Box et al. 1976), which was the first time that yields on unirrigated land in this area had reached those levels. A substantial portion of this high yield was attributed to sustained high infiltration rates and lowered evaporation rates, which made more of the water available for crop use, compared to available water in conventional tillage systems. No-till planting into sod is a cost-effective means of erosion control in this region, which can be used to bring CRP and other grasslands into production as needed. As shown by Lindstrom et al. (1994) and discussed in chapter 16 here (long-term effects of tillage), no-till management retains most of the benefits accrued by soils during their tenure in grass.

Systemic herbicides can be used to obtain a good kill of the grass after it has been cut and begins vigorous regrowth. However, if the grass is dormant or under stress, such as may occur in regions where water is limited in summer and fall, then a systemic herbicide will give poor control. In these situations the grass must be killed by tillage, or the herbicide must be applied before water stress induces dormancy.

In situations where cool- and warm-season grass species are growing together in CRP land, two applications of a systemic herbicide may be needed to avoid dormant periods of the different grasses.

Recognizing that farmers growing winter wheat need to plant in fall and need to prepare land before the wheat is seeded, the current CRP rules allow farmers to begin such preparation, including tillage, up to 3 mo before the October 1 release of such lands. If tillage (which buries the residues and disrupts and displaces the sod fabric) takes place, it will expose the soil to erosion and promote rapid decreases in organic matter and infiltration. However, if the needed killing of the grass is accomplished with a herbicide, the grass residues and sod will remain in place and protect the soil from erosion during the period it is accumulating the water needed to germinate the seed and facilitate the growth of the following crop. Many studies have shown that the slowly decaying residues and sod will keep infiltration rates high and will control erosion for at least a year following the killing of the grass.

One challenge that may occur when planting without tillage on land that is coming out of the CRP is how to deal with established burrowing animals and the damage they may have caused during the 10 yr of grass. These animals may leave the soil surface quite rough (Kalisz and Stone 1984). The tendency is to moldboard plow the area before starting no-till. In extreme situations this may be required, but normally tillage is not needed. Once the grass is killed and a crop has been planted, the food source is removed, the animals disappear, and the mounds tend to level within a year.

Nitrogen management on no-tilled former CRP lands also needs special attention because of changes in nitrogen mineralization patterns (Wood et al. 1991a, 1991b; Lamb et al. 1985). As tillage is imposed on sod, a flush of microbial oxidation and mineralization of organic nitrogen may occur. As tillage intensity is reduced, the microbial oxidation of organic matter decreases and more of the organic nitrogen is retained in the soil organic matter. Soil testing is critical, and the subsequent soil-fertility recommendation must take into account the effects of the 10 yr of grass and lack of a primary tillage operation. No-till into sod will initially require higher nitrogen rates than if the field is moldboard plowed (Thomas et al. 1973), because the plowing accelerates biological decomposition of the organic matter and mineralization of its nitrogen.

Design of No-Till Systems

No-till systems must be designed according to the unique conditions of the geographical region and the specific needs of the individual producer. Therefore it is not possible to design a no-till management system that can be applied to all locations across the United States or even within a single region. A successful no-till system must be developed from a whole-system point of view. Three factors that need to be considered when designing a no-till system are rotation, sanitation, and competition to help control weeds, insects, and pathogens (Beck and Doerr 1990). Although the specific cultural practices required for each region and farm are likely to vary according to climate, crop, and local markets, these three broad-based principles are common to the successful establishment of no-till crops. Other chapters in this publication provide additional details on how to adapt no-till and other types of crop residue management to specific soil, climate, and crop situations.

Sanitation involves practices that reduce the movement and spread of pests (weeds, diseases, and insects) into a field. An example is the prevention of perennials from producing seed in the field borders by mowing. Another is the use of disease-free seed. Many agronomic practices of sanitation are well known. The importance of following these practices is more critical in no-till systems because they do not involve tillage, which can help reduce the population levels of some pests.

Rotation is especially critical to a properly designed no-till system. Rotation can be beneficial in controlling weeds, diseases, and insects by breaking the life cycles that depend on compatible crops or by increasing the competitive pressure on a pest during part of the rotation. An example is the use of a corn-small grain-soybean rotation to protect against corn rootworm infestations by means of an extended diapause. The use of rotations in no-till generally helps create a stable, low-maintenance cropping system. The design of rotations should consider the best cropping sequence for control of diseases, weeds, and insects; soil temperature at planting; seed zone moisture content; residue cover for erosion control; and labor and equipment use. As a field comes out of grass sod into crop production, the rotation principle can be applied immediately by choosing a broadleaf species (such as soybeans or cotton) as the first crop. These crops will not generally succumb to or be a host for the diseases that had infected the grasses. Weeds, including escaped grass, will be easier to control in the broadleaf crop than in a small-grain crop. An additional safety factor with the use of legumes as a first crop is that their growth will not be appreciably restricted if the rapidly decaying grass depletes the soil nitrate supply.

Competition involves the ability of the crop to outcompete weeds for light, water, and nutrients. An example of favoring a crop in such competition is the use of narrow row spacing to achieve earlier crop canopy cover. Cover crops may also be used in the more humid regions of the United States to compete with weeds, add nitrogen, and protect the soil during periods when cash crops are not growing.

No-till equipment has been designed for most crops. Care still needs to be used in selecting no-till equipment to ensure that approved methods of chemical application are compatible with the equipment selected. Also, equipment modifications may need to be made regionally, depending on climate and soil-specific problems. For example, in the northern parts of the Corn Belt and the Cotton Belt, row-clearing attachments may be needed to remove some of the residue from the row area. Removing some residue allows the soil to warm up so that seed emergence is improved, especially in poorly to somewhat poorly drained areas.

Other aspects that should be included in the design of a no-till system are equipment use, livestock needs, personal preferences of the producer, cash-flow requirements, market availability, predictable climatic patterns, proximity of the water table to the surface, soil fertility, and risk management. Planners of no-till should study management practices and equipment that are adapted to the regions, and they must develop practices and modify equipment to adapt to the unique characteristics of their individual sites.

Conservation Measures for Residue-Deficient Crops

When the primary crop needed by the farmer is a residue-deficient crop such as cotton, peanuts, or silage corn, there may not be sufficient residue during the following year to provide the mandated erosion control. As discussed in chapter 14, cool-season cover crops are often a good provider of the needed protection. Where growth of cover crops results in water deficiency or is otherwise not feasible, grass hedges can often complement no-till management to achieve the needed erosion control. This is because the hedges retard runoff, pond the water where they intercept flow concentrated in rills and gullies, and retain most of the sediment (Kemper et al. 1992). To be effective, in the concentrated flow channels, the grasses in these hedges should be stiff stemmed and tall because they must stand erect to achieve the needed retardation of the flow (Dabney et al. 1993). In the few cases where the grass planted into CRP lands has tall and stiff stems (for example, switchgrass or eastern gamagrass), the needed hedges can be achieved by leaving 2- to 3-ft-wide strips of grass between planned cropped areas in strips whose width is about ten times the grass height.

If grass on CRP land is not sufficiently stiff and tall to provide the retardation and dispersion of the concentrated flows, the CRP rules allow improvements of the cover during the contract period. Because most perennial grass species require about 2 yr to reach maximum stature and to get their roots below those of annual crops, the rows of tall grass for hedges will be better prepared to thrive and to protect the cropped area if they are planted a year or two before the crops are to be planted. This can be accomplished by killing narrow strips of the short grass with herbicides and planting those areas with the desired tall, stiff-stemmed grasses. When these hedges have reached the desired height and the CRP contract rules allow killing the grass in preparation for planting the crop, the rest of the short grasses in the planned crop strips between the hedges can be killed. To avoid the possibility of being considered in violation of CRP rules, installing tall-grass hedges in CRP lands should be discussed with your SCS District Conservationist and incorporated into your plan before killing strips in the short grass.

Costs of this additional improvement of CRP lands to provide tall-grass hedges for the erosion control of subsequent croplands cannot be shared by CRP. However, since less than 10 percent of the area is in the grass hedges, the cost for herbicide and seed is small. Additional reductions in costs may be achieved by installing stiff tall-grass hedges in the concentrated-flow areas and leaving short-grass hedges in areas of the field that will not experience concentrated flow.

The benefits of grass hedges for the control of both wind and water erosion are discussed in chapter 15. Although game birds have been observed nesting and overwintering in tall-grass hedges, the effects of these hedges on bird populations have not been systematically evaluated.

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16 Long-Term Effects of Tillage and Crop Residue Management

W.C. Moldenhauer, W.D. Kemper, and G.W. Langdale

Genesis and Degradation of American Soils

When Europeans arrived in America, they found soils that were a result of climate and vegetation interacting with the geologic minerals. Leaves and other residues fell to the ground and decayed, and part of their decomposition products leached into the soil. Roots grew, died, and decayed, also contributing to building the organic matter and associated elements that nurtured the natural succession of plants. Among these plants were legumes that provided photosynthate to bacteria infecting their roots; these bacteria were able to take nitrogen out of the air, fix it in ammonium, and share it with their host plants. Primarily as a result of these legumes, about 6 percent of the residual organic matter in soils is nitrogen. Other plant nutrients extracted from the soil and air and incorporated into the plants also became part of this soil organic matter. Although most native Americans were crop growers, there were few. Their methods of crop production involved little tillage. Competing weeds were removed largely by hand.

Friendly natives taught the newly arrived Europeans how to grow corn in the early 17th century. With their iron mattocks and hoes, the Europeans were able to control weed growth more efficiently than were the natives. Within a few years, corn was the staple of their diet, and they were growing enough corn to trade it for animal furs. The arrival of draft animals, cultivators, and plows gave the Europeans additional ability to control weeds. These implements also stirred and aerated the soil, buried crop residues, and stimulated microbial activity, which increased the breakdown of the residual organic matter and liberated its nutrients for use by the crops. Since there were no commercial fertilizers, this accelerated decomposition of organic matter was the primary source of plant nutrients in those early years.

In the 19th century John Deere developed the moldboard plow, which turned the soil over completely and buried almost all of the crop residue. It became the most popular implement for primary tillage. The complete burial of the crop residue and the decreasing residual organic matter exposed soils to the beating action of raindrops; this action destroyed soil aggregates, filled the large pores, and reduced infiltration—all of which caused runoff and erosion. Erosion by runoff water carried away substantial portions of the topsoil in the eastern and southern United States where rainfall rates were high. In the more arid western plains, the burial of plant residues and the subsequent impact of rain created smooth surfaces along which the wind blew the sand grains; the sand literally sandblasted the soil, enabling the wind to blow away major portions of our topsoils.

Early in the 20th century, concerned farmers and Government officials recognized the rapid degradation of our soils from erosion and initiated research and plans to reduce erosion. In the 1920's and 1930's, rotations, stripcropping, and mulch tillage were evaluated. These techniques involved chisels and blades that sliced under the surface and killed weeds but left most of the wheat stubble on the surface. They obviously helped to reduce the erosion from wind and water. It took longer to observe their effects on organic-matter content and fertility of the soil. Long-term studies were initiated at several locations across the country. In 1876 at the University of Illinois in Urbana, Professors Manley Miles and George E. Morrow established a crop management study that has become internationally known as the Morrow Plots (Odel et al. 1984). The soil organic matter was about 6 percent when tillage was initiated. Continuous corn, involving plowing each year since 1876, has reduced the organic matter content to less than 3 percent (fig. 1). The best rotations reduced the rate of depletion, and legumes in those rotations helped maintain soil fertility; but the levels of organic matter still continued to decline as long as plowing continued.

At Pendleton, OR, on grassland where tillage was initiated in 1881, the residual-organic-matter content of soil under grass was reduced under moldboard plowing, which accelerated the runoff, erosion, and loss of fertility. Consequently, in 1929 researchers began evaluating a series of crop-residue management treatments ranging from burning the residues to plowing 10 tons of manure plus the crop residues into the soil each growing season. Refraining from burning slowed the decline of residual organic matter, and during the first 20 yr the heavy manure addition each year seemed to slightly increase the organic-matter content (fig. 2). However, even with 11–12 tons of organic residue plowed into the soil each growing season, the residual-organic-matter content has not increased during the past 40 yr (Rasmussen et al. 1989).

Reicosky and Lindstrom (1993) measured the carbon dioxide given off in fields for 19 days after wheat stubble had been moldboard plowed, chisel plowed, disked, or left standing with no-tillage. As shown in figure 3, the amount of carbon oxidized was greatest in fields that had been moldboard plowed. In 19 days, as much carbon was oxidized as had been photosynthesized and incorporated into the residues and roots during the whole growing season. A large portion of the crop residue had not completely decomposed at the time. Consequently, it appears that easily decomposable portions of the fresh residue provided food to generate high microbial populations; these found access to residual organic matter in the plowed and highly aerated soil, and oxidized substantial amounts of it out of the soil. When one realizes that microbes can oxidize a couple of tons of organic matter in 19 days following moldboard plowing, one can see how the 12 tons plowed into the Pendleton, OR, plots could be oxidized each crop year for the past 40 yr.

Other types of tillage resulted in lower biological oxidation rates than did moldboard plowing (fig. 3). Their use is helping to slow the rate at which residual organic matter is being oxidized out of our soils. However, during the 19-day study period, the oxidation of organic matter from all the tillage treatments was much more than that from the no-till treatment.

Effects of Reducing Tillage on Residual Organic Matter

The development of wide V-blade sweeps, rod weeders, and other equipment that disrupts the soil and undercuts weeds while leaving most of the crop residue on the surface has helped to control erosion (Lindstrom et al. 1974). As relatively low-cost fertilizers became available in the 1960's, however, it was no longer necessary to till and oxidize organic matter to release nutrients needed by our crops. The development of herbicides provided an alternative to tillage for weed control. As conservation-minded researchers and farmers saw the improved erosion control from leaving residues on the surface, they used these alternatives and reduced the tillage. Some of them reasoned that it was now possible to grow grain crops much the same way they grow in natural ecosystems, where there is no tillage.

In these natural systems, when vegetative growth was good and burning did not occur, the soils generally had continuous cover and protection from the forces of wind and water. The major obstacle remaining to the achievement of no-till production systems was getting seed through the surface residues and into the soil. Equipment companies helped to develop coulters, seed-placement devices, and press wheels that cut through the residues without disturbing them appreciably and pressed seed into good contact with the soil. The development of no-till drills and seeders provided an alternative to seedbed preparation, the other major purpose of tillage. With these alternatives available, thousands of fields were soon managed without tillage.

The erosion-control benefits of no-tillage were immediately obvious. Researchers documented that no-till reduced erosion to 20 percent of that occurring under moldboard plowing systems or even eliminated it. By removing crop residues from some of their no-till plots and observing erosion during rainstorms, they found that the absence of tillage, in addition to keeping protective residues on the surface, leaves the soil more cohesive and more resistant to the erosive forces of water. Laboratory measurements showed that bonding forces between soil particles decrease with tillage and increase with time following tillage. The root fabric and the high residual-organic-matter content that develops in the immediate surface under no-till will reduce the slaking and disintegration of aggregates when they are wetted.

In the past, scientists felt that incorporating crop residues into the soil was the way to get organic matter into the soils where it could become part of the residual organic matter. Reicosky and Lindstrom (1993) showed that this intuitive feeling was wrong. In fact, incorporating crop residues into the soil by moldboard plowing accelerates the rate of oxidation of both the crop residues and the residual organic matter, as discussed previously.

Farmers practicing no-till management are noticing that their soils are becoming darker and richer in organic matter. Researchers in Ohio, Georgia, Alabama, and Colorado measured residual organic matter in these no-till soils and found that it was increasing. When no-till management was practiced for 10 or 20 yr, the residual organic matter in the top inch of soil could rise to over 10 percent (Edwards et al. 1988). However, there was little change below 3 inches. Minor tillage such as light disking (used by Wood and Edwards 1992) mixes the organic matter deeper into the soil (fig. 4) but also causes more rapid oxidation of the organic matter.

George Langdale and Bill Edwards both concluded (personal communications 1994) that organic matter in the top inch of soil is strategically positioned to cause less evaporation and to increase infiltration than when the organic matter is mixed by tillage to a depth of 8–10 inches. Consequently, they believe that leaving soil on the surface is a strong contributor to long-term increases in productivity (discussed later in this chapter).

Effects of Increasing Surface Residues on Residual Organic Matter

Measurements of residual organic matter in soils during 10 or more years of no-till management indicate rates of increase ranging from 200 to 1,500 lb/acre/yr. These rates depend on how much crop residue was left on the surface. The highest rates occur where crop residues were augmented with winter cover crops left on the surface (Langdale et al. 1992b). The lower rates were from drier warm regions where the amount of crop residues was limited and high temperatures caused rapid biological oxidation of the organic matter.

In areas where residual organic matter is low, organic wastes such as paper and manure have been placed on the soil surface or plowed into the soil to help increase the organic matter. The greatest sustained increases are resulting from leaving the organic wastes on the surface (Lu et al. 1994a, 1994b).

The elimination of tillage will increase the amount of organic residue on soil surfaces, decrease the biological oxidation rates of residual organic matter, and reduce the soil erosion—all of which cause net increases in the residual soil organic matter. No-tillage and reduced tillage can conserve our soils, but they can also enhance them so that they will be able to sustain the world's population.

Effects of Leaving Crop Residue on the Surface

Effect on Soil Fertility, pH, and Rooting Depth

***Fertility*.** One early concern about no-tillage was getting fertilizer and lime from the surface down to the crop roots. To some extent, the feeder roots of crops solve this problem by nearing the soil surface where the soil is moister because crop residues reduce the evaporation.

Phosphorus was also expected to be a problem because it is normally adsorbed and is relatively immobile in soils. However, as Kunishi et al. (1986) found, phosphorus apparently forms complexes with organic matter when left on surface residues, and those complexes leach into the underlying soil where they are readily available to feeder roots. Through mycorrhiza (beneficial association of fungal mycelium with the roots of a weed plant), fungi extend their slim hyphae into the soil and allow plants to draw phosphate from those parts of the soil their roots cannot reach directly. More of these hyphal conduits remain intact when tillage does not occur. Crop roots in no-till soil tend to follow the root channels of the previous crop, which enables these new crop roots to more quickly extract water, phosphorus, zinc, and many other elements from the soil (Vivekanand and Fixin 1991).

***pH*.** Calcium has historically been observed to stay close to lime placements in soils, raising questions about whether lime applied on the surface would stay there and leave the underlying soils excessively acid. Some of the early no-till researchers found that the immediate surface of no-till soils became acid sooner when lime was applied on the surface than when equal amounts of lime were mixed through the plow layer. In long-term no-till fields where lime, crop residues, manure, and nitrogen fertilizer were all left on the surface for 24 yr, the acidity of underlying soils was neutralized to a depth of about 70 cm, compared with 30 cm in fields where soils were plowed and lime was mixed in (Edwards et al. 1988) (fig. 5).

The mechanisms by which the calcium in the lime is mobilized is probably influenced by the proximity of the crop residues, nitrogen fertilizer, and lime at the surface. As microorganisms nitrify ammonium fertilizers to nitrates, acid hydrogen ions are produced that tend to solubilize the calcium in lime when it is close to the fertilizer. The slow and relatively continuous biological breakdown of the surface residues produces a continuous source of organic anions, which along with the nitrates facilitate the downward leaching of the positively charged calcium, aluminum, and hydrogen ions in the soil.

Researchers have been trying to get more calcium into subsoils for years because they recognized that raising the pH causes subsoils to be more hospitable to roots. Deep plowing and the mixing of lime into the subsoil worked but were too expensive. However, these benefits can occur as a side effect of no-till, which leaves all the residues, fertilizer, and lime on the soil surface. When the nitrogen fertilizer is knifed into the soil, the subsoil pH tends to increase; but the moderation of subsoil acidity with this technique is less than that noted when nitrogen fertilizer is applied on the soil surface.

***Rooting depth*.** Sumner (1990) was able to increase the alfalfa rooting depths in acid soils by 50 percent by getting calcium into the subsoils with gypsum applications that left the subsoil undisturbed. Wang et al. (1986) found that earthworm burrows in the soil facilitated the deeper rooting of soybeans. Because long-term no-till management generally increases the earthworm populations and the depth of calcium penetration, these two factors probably act together to facilitate the deeper rooting. Deeper rooting provides the plants with access to more soil water, and this access may help account for the increased drought tolerance of crops grown under long-term no-till management on fields that initially had acid subsoils.

To take advantage of the greater growth potential from the additional water conserved, additional fertilizer is commonly needed during the first few years of no-till. The quantity of nitrogen fertilizer needed may decrease after several years in minimum-till or no-till systems as the residual organic matter becomes sufficient to supply more nitrogen for plant use.

Effect on Infiltration, Evaporation, and Water-Use Efficiency

The most direct and measurable effect of keeping crop residues on the soil surface is the improvement of the water-use efficiency of acid and calcareous soils. In many areas, the increases in infiltration rate and the decreases in evaporation occur within a year or two, as discussed in previous chapters. However, in soils where earthworm populations have been decimated by intense cultivation or harmful pesticides, it may take many years for earthworm populations to increase to the point that their burrows to the soil surface contribute significantly to infiltration.

In a series of small watersheds near Coshocton, OH, it took earthworms 6–7 yr to return in large numbers after the beginning of no-till management (Norton and Schroeder 1987) (fig. 6). Data were based on measurements of pores larger than 0.5 mm at the soil surface before and during 21 yr of no-till. Pores of this size are highly effective in letting water through surface seals into the soil. Earthworms and recent cultivation are commonly responsible for such large pores. Following the cessation of cultivation, the percentage of surface occupied by these large pores declined for 5 yr. Only when the earthworms returned in large numbers did their burrows furnish the large pores that contribute to the rapid entry of water in this soil.

The return of earthworms has been hastened by collecting buckets of them from lawns and the edges of rural roads during or immediately after rains and then depositing them in groups of four or five in new no-till fields (James Kinsella, personal communication 1994). They will invade a soil at the rate of about 50 ft/yr when conditions favor their growth. However, the earthworms' lack of a specific urinary tract leaves urea on their skins, which hydrolyzes to ammonia and irritates them. Consequently, they are attracted to moist soils where they can more quickly rub off the urea and ammonium and also to the soil surface during rainfall where the rain washes the compounds off. The tendency of the worms to come to the surface during rainfall contributes to their migration during runoff events, when they float downhill. In runoff plots at Kingdom City, MO, as many as 900 earthworms washed off a 945-ft^2 plot in a single rainfall. The average rate of downstream transfer is generally lower than that given in this example, but introducing worms on the higher portions of fields can significantly increase their rate of invasion of the whole field.

As soon as crop residues provide cover for most of the soil surface for a significant part of the year, they help reduce evaporation from the soil. Long-term no-till growers report that the amount of crop residue returned to the field increases with time for 10 or more years as crop yields increase. However, some long-term no-till growers have noted that when large populations of night-crawler-type earthworms collect residues in their middens, especially after soybeans, this causes a more rapid removal of cover from the soil. Fortunately, this process usually does not completely remove cover until the crop canopy has begun to protect the soil from the impact of raindrops. Even when the lack of surface cover allows a major portion of the soil surface to seal, if there are several earthworm middens or holes per square yard, they will drain most of the water accumulating on the surface into the soil, and thus minimize runoff.

Another long-term effect of surface residues, which will contribute to water-use efficiency, is the accumulation of residual organic matter. As discussed previously, this is a slow process, occurring at a rate of about 1,000 lb/yr under good no-till management. At this rate, it takes 20 yr to increase the organic matter content of the top 6 inches of soil by 1 percent. In soils like those in the Morrow plots in Illinois, which now have only 3-percent organic-matter content, it may take a century of good no-till production to restore the organic matter to the initial 6 percent. Analyses by Hudson (1994) showed that the available water-holding capacity of loam soils increases by almost 4 percent of the soil volume for each additional percentage of residual organic matter. For farmers who have topsoils with low organic matter and water-holding capacities of 10–12 percent, this gives them the potential of increasing those capacities to 14–16 percent in 20 yr. If this organic matter buildup and increased water-holding capacity are restricted to the top 6 inches of soil, the soil will hold an extra 1/4 inch of water each time it dries out and is refilled by rain. Thus, the total amount of extra water held during all the refills in a growing season will be only 1–2 inches. However, most of the crops' feeder roots are in this layer, so crops will have better access to nutrients as well as to water during drought-stress periods.

Effect on Crop Production

Factors that increase the units of crop produced per unit of precipitation received are as follows: significantly increased infiltration, decreased evaporation from soils, increased water-holding capacity, increased snow catch and deeper rooting associated with no-tillage, and retention of surface residues for extended periods (Langdale et al. 1994).

Higher residual organic matter in soil also increases the soil's general fertility and productive capacity. Soil organic matter acts as a "bank" where nutrients may be deposited in times of surplus and withdrawn when rainfall or irrigation has leached out most of the soluble and mobile nutrients (especially nitrates) from the soil. Temporary nitrate deficiencies will not reduce crop growth nearly as much in soils with high organic-matter content (where microorganisms are slowly and continually drawing nitrogen from the "bank") as in soils with low organic-matter content.

Residual organic matter, derived from plants, includes most of the elements essential for crop production, and its slow decay provides a limited but continuing source of these elements. The slow decomposition of this organic matter also furnishes a host of organic molecules or fragments that act as carriers, enabling micronutrients absorbed in the soil minerals to reach the roots. Unlike no-till, tillage accelerates the rate at which nutrients from crop residues and residual soil organic matter are mineralized or made available to crops. If the crop is not ready to use the nitrates, they are at risk of being leached out of the crop root zone by rain. In many respects, the tillage of soil is like stirring the coals, putting in kindling, and opening the draft of a coal or wood stove: tillage accelerates the oxidation of organic matter, quickly liberating its components to the surrounding environment.

Organic matter darkens soils because they are absorbing more of the sun's radiation, and soils that absorb more of the sun's radiation are warmer. Because crop residues reflect more of the radiation, covered soils stay cooler; this decreases the plant growth in the cool early spring but may be better for crops in the late spring or early summer before the crop canopy provides shade. Long-term residue cover darkens the surface of most soils so that they resemble the black chernozems of the Midwest. Farmers who want the higher temperatures in dark soil to facilitate crop growth during spring can use equipment on their tool bars to move the residue off the seed rows before or at planting time. This residue removal also permits the continued use of conventional seeders for farmers who do not own no-till seeders.

In fields where all residues are left on the surface, the crop yields may be reduced by cooler spring temperatures under the residues, by outbreaks of disease and insects in the monoculture, and by occasional lapses in weed control. However, on most soils the long-term benefits of no-till (including increased residual-organic-matter content, improved water-use efficiency, and possibly increased experience of the no-till manager) generally result in greater productivity (over time), compared to the productivity of tilled fields (fig. 7).

Effect on Erosion Control

Residue cover achieves substantial erosion control by (1) intercepting the impact of raindrops, slowing surface sealing, and sustaining higher infiltration; (2) causing water to pond on the surface, which causes wormholes and other micropores to become avenues for infiltration; and (3) causing settlement of sediment in the temporarily ponded water (Langdale et al. 1992a, 1994).

Refraining from tillage allows long-term mineralogical processes to strengthen with time (somewhat similar to the processes that cause moist concrete to strengthen). In most soils, long-term no-till management increases the populations of earthworms and associated macropores, which in turn increase the infiltration and reduce the runoff and erosion. Long-term no-till causes major changes in the organic matter of the immediate soil surface so that it is much more resistant to slaking and aggregate disintegration and has higher infiltration rates.

Reasons for Limited Tillage

There are still legitimate arguments for limited tillage, as follows:

- In some cases the cost of a nutrient form, such as the anhydrous form of ammonia, is considerably lower than the cost of another nitrogen fertilizer, and this savings justifies the limited degree of cultivation needed to apply it.

- Deep chiseling or paratilling of soils to help the crop roots get past the restricting layers will benefit the yields in some areas, especially in the southeast.

- As mentioned, ridge- or row-till equipment can push residues off the planting strip for row crops, allowing the use of conventional planting equipment and also warming the soil to accelerate early growth. This principle applies to cotton in northern Alabama.

- Under some climatic conditions, weed and grain seeds need a light soil cover to help them germinate so they can all be killed by one herbicide application before a long fallow season or planting the next crop.

- In some special soils there is evidence that tillage can break the capillary pore connections between the soil water and the surface, thus keeping slightly more water in the soil during long, dry, hot summer fallow periods.

- During the initial 2 or 3 yr of no-till, before sufficient soil cohesion has developed to support the weight of equipment, the soil may become so compacted and rutted during harvest in wet weather that tillage is necessary to break up the compaction and smooth the soil surface.

- Some state and regional regulations require the burial of specific wastes and crop residues to control specific insects and diseases. However, in some cases there are alternatives. In the southeast, for example, the flail mowing of cotton stalks is sufficient to control cotton insects.

Each farmer must balance these arguments for cultivation against the damage that cultivation does by reducing the residual organic matter and reversing the benefits of crop residue management. One of the most critical economic factors that needs to be considered is the degree to which tillage will destroy soil cohesion, crop residue cover, and erosion control as computed by Soil Conservation Service (SCS) guidelines and equations. The economic consequences of failing to be in conservation compliance will be devastating for most farmers enrolled in Government programs. Consultation with SCS technicians may help farmers avoid the loss of both erosion control and crop support payments.

Effects of Herbicides on the Environment

Concern has been expressed in some public sectors that the long-term use of herbicides rather than tillage for weed control will add manufactured chemicals to our soil, air, and water and thereby degrade them. A broad survey by Bull et al. (1993) indicated that corn growers used about equal amounts of herbicides on tilled systems and no-till systems. This is in keeping with the observation that most farmers recognize that herbicides are often the most cost-effective means of weed control. In 1990, herbicide use on no-till soybeans was about 56 percent higher than on conventionally tilled soybeans; by 1992, the use on no-till averaged only about 13 percent more. In 1994, long-term no-tillers said that they are using less herbicide than when they started no-till and often even less than when they were tilling. During the last 6 yr, the adoption of no-till has doubled every 3 yr; because half of the no-till farmers reported by Bull et al. (1993) were still in the initial 3-yr learning stage and only 25 percent had a minimum of 6 yr with the system, we anticipate that the amounts of herbicides used in no-till farming will continue to decline.

A factor that plays a significant role in the herbicide contamination of water is the use of soil-incorporated (preemergence) herbicides, as differentiated from direct-contact (postemergence) herbicides. Preemergence herbicides are the more common choice of conventional tillers. The most effective preemergence herbicides are chemicals that are mobile (not adsorbed) in the soil and that persist for long periods before they degrade. In contrast, many of the postemergence herbicides are sprayed directly on the weeds, strongly adsorb (adhere) to soil if they miss their target, and rapidly hydrolyze or biologically degrade when they contact the soil. These postemergence herbicides are becoming less expensive and the more common choice for no-till management.

Reduced tillage keeps topsoil on the land and out of streambeds, reservoirs, and lakes. Where no-till increases the infiltration, the reduced flood damage, increased groundwater recharge, and increased base streamflows improve the environment. In monitored watersheds where surface sealing from conventional tillage caused 10-30 percent of the precipitation to run off, the long-term no-till often reduced runoff to negligible levels.

As water runs off, it carries feces from domestic and wild animals, disease organisms, and a host of organic compounds, of which over 99 percent are of natural origin and fewer than 1 percent are of manufactured origin. Surface runoff that enters reservoirs is so heavily laden with contaminants that standard rapid filtration does not remove all of them. Chlorination is commonly required to kill the pathogens before water can be used for drinking, but the chlorination of humic acids and natural organic compounds can increase their carcinogenicity. When reduced tillage enables all precipitation to enter the soil, the pathogens and other organic compounds are filtered out as the water percolates slowly down, and the water that enters aquifers is generally of good drinking quality.

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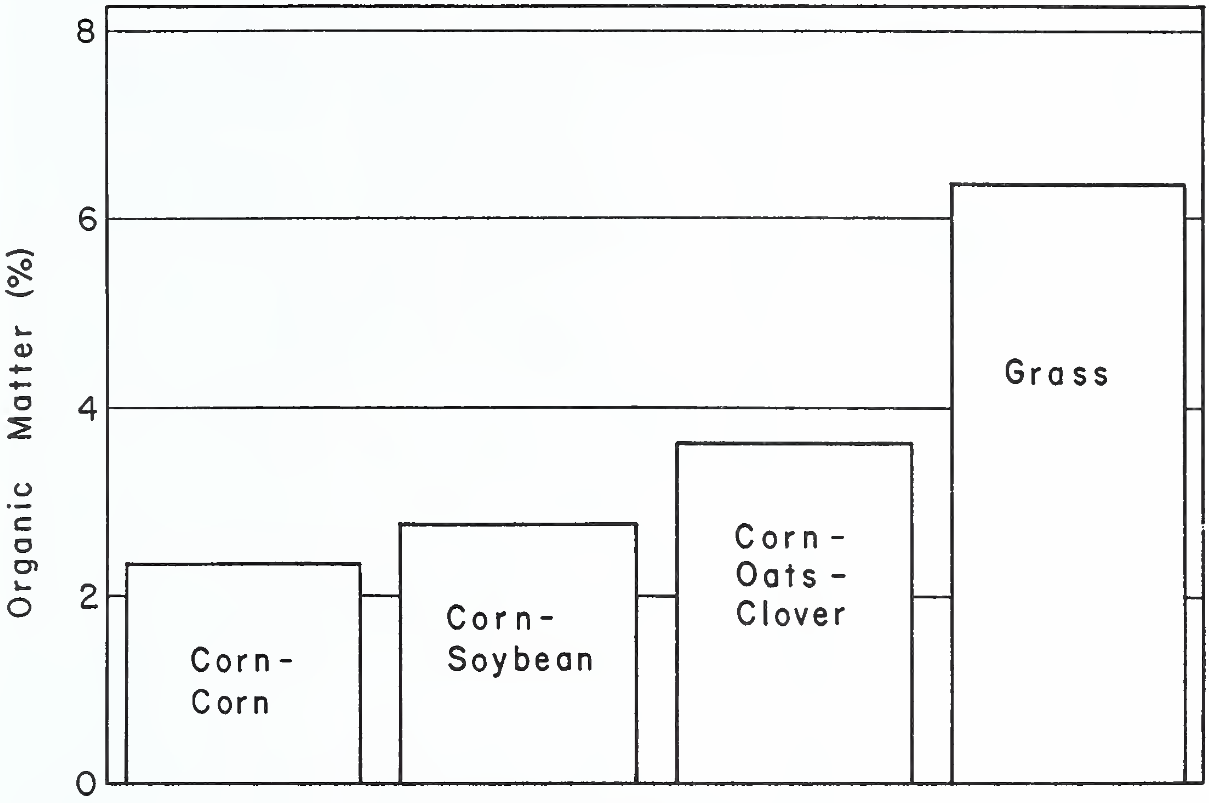


Figure 1. Organic matter in moldboard-plowed soils after more than 100 yr in indicated rotations and adjacent untilled grassland. Source: Odell et al. 1984.

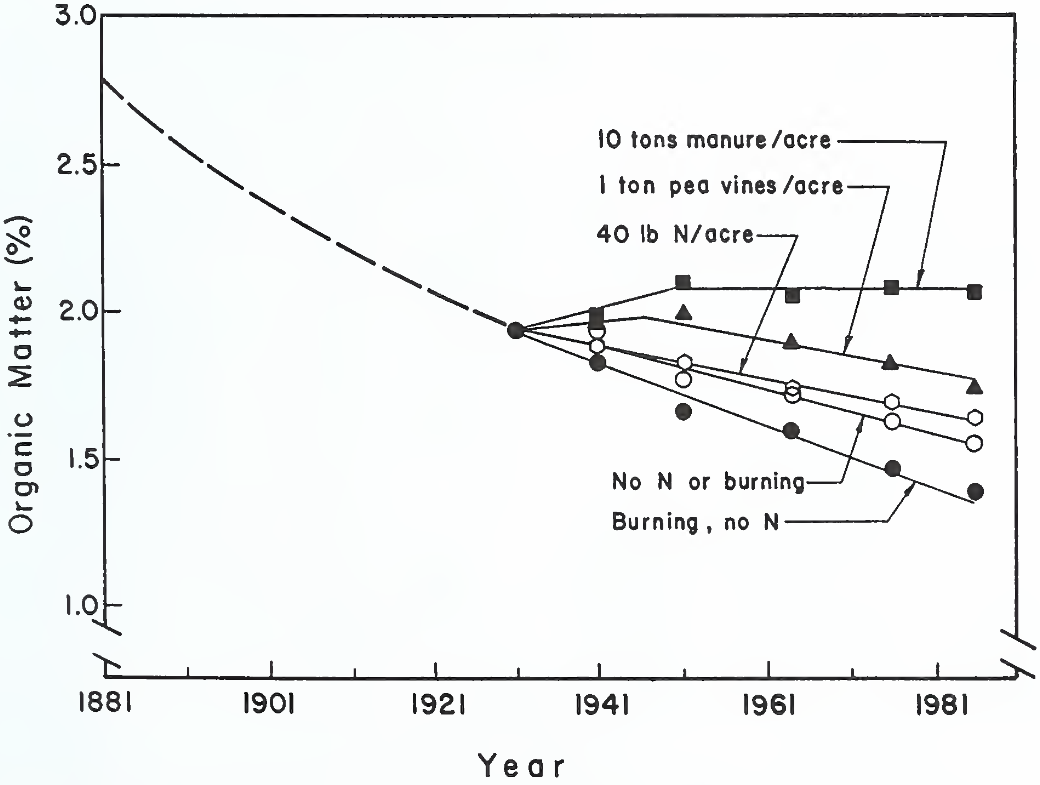


Figure 2. Effect of management practices on long-term changes in organic matter in the top 30 cm of a Haploxeroll soil in Oregon. Source: Rasmussen et al. 1989.

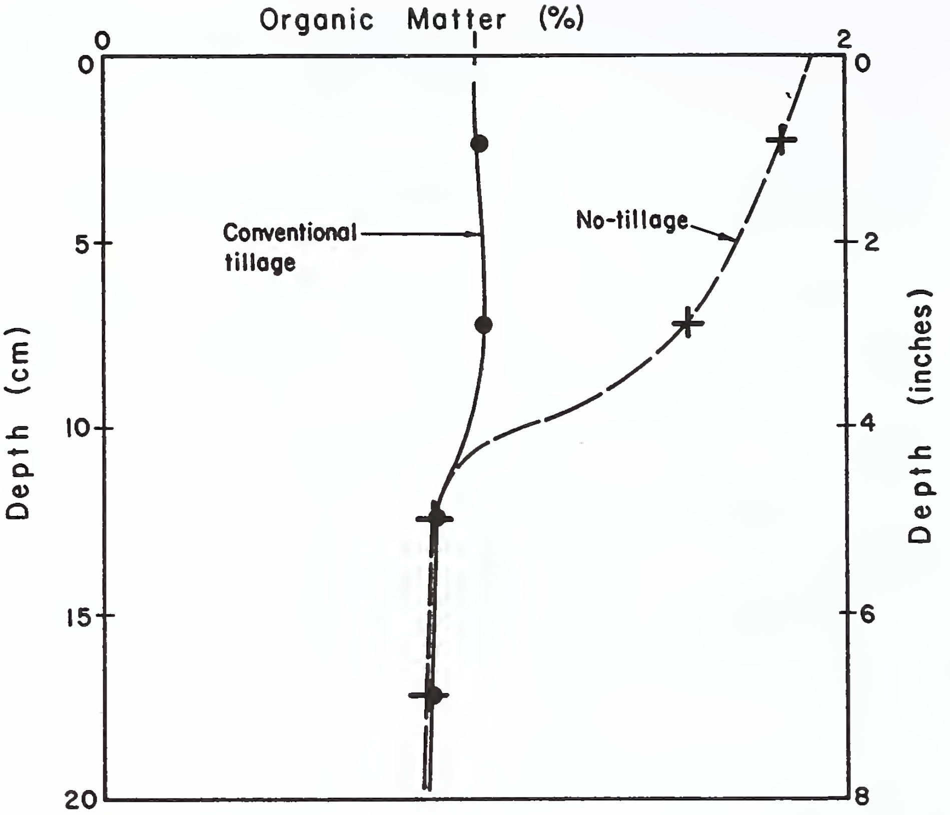


Figure 3. Organic matter oxidized in 19 days in September following various tillage operations on wheat stubble in Morris, MN. Source: Reicosky and Lindstrom 1993.

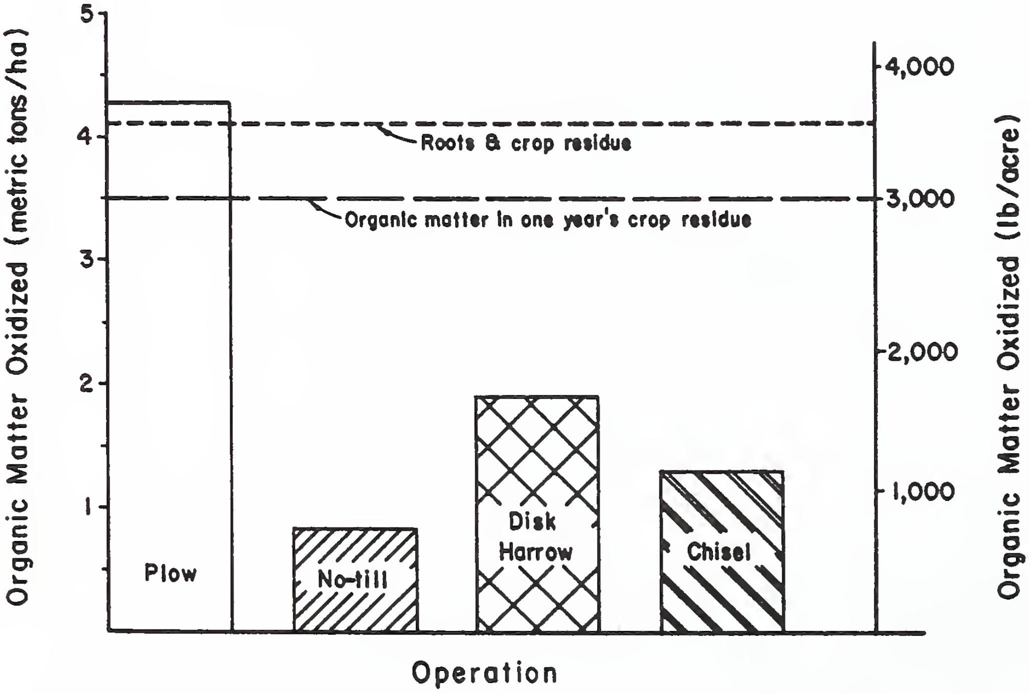


Figure 4. Comparison of organic-matter content at various soil depths after 10 yr of a conventionally tilled and a no-tilled corn-wheat-soybean-wheat rotation in Crossville, AL. Source: Wood and Edwards 1992.

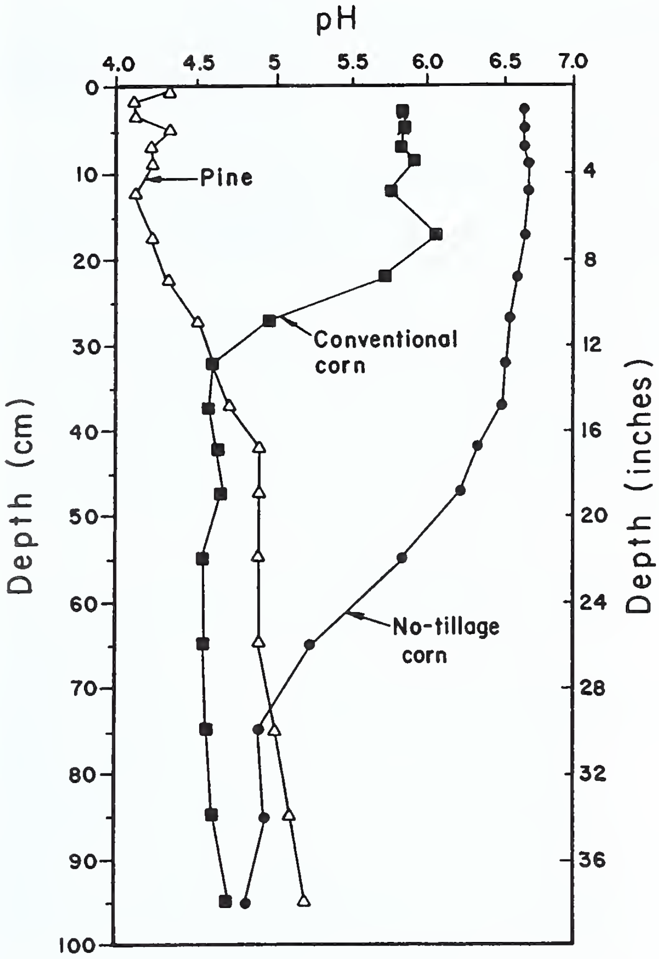


Figure 5. Effect of conventional and no-till corn on soil pH at various depths. Each distribution is the average of 8 replications. Source: Edwards et al. 1988.

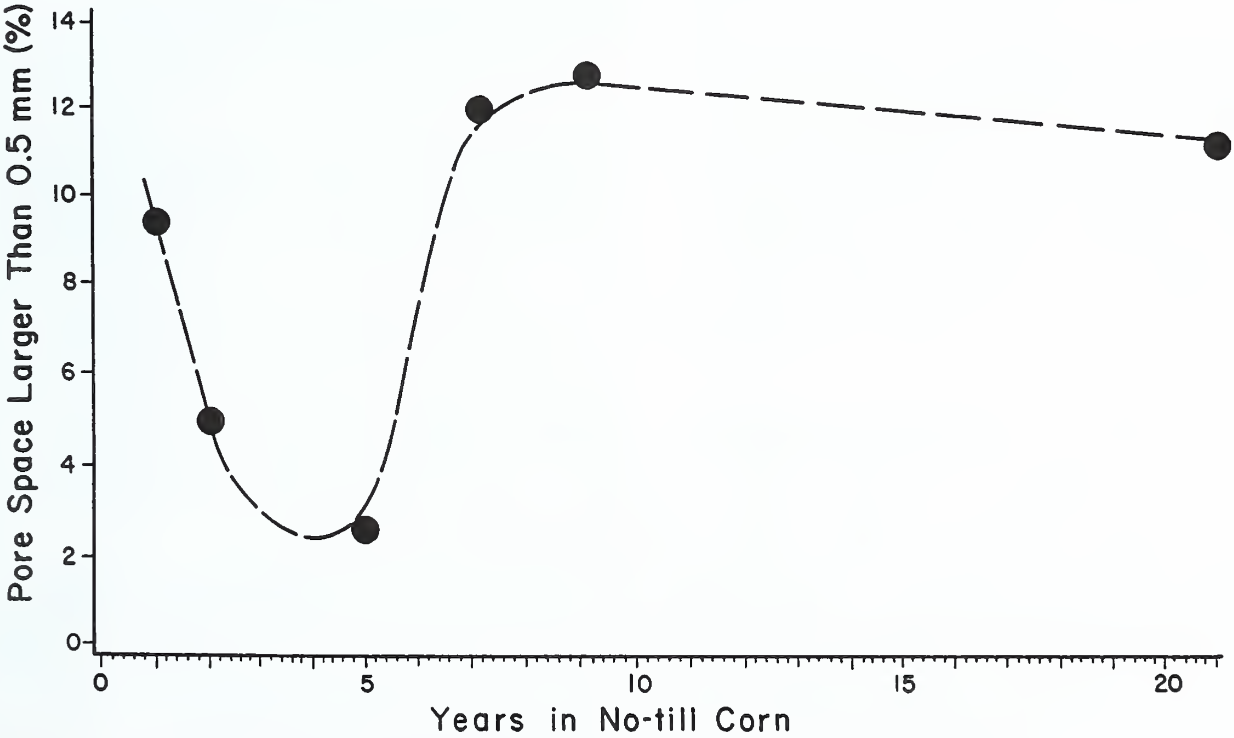


Figure 6. Changes in soil surface pores larger than 0.5 mm in diameter after beginning no-till management in Coshocton, OH. Source: Norton and Schroeder 1987.

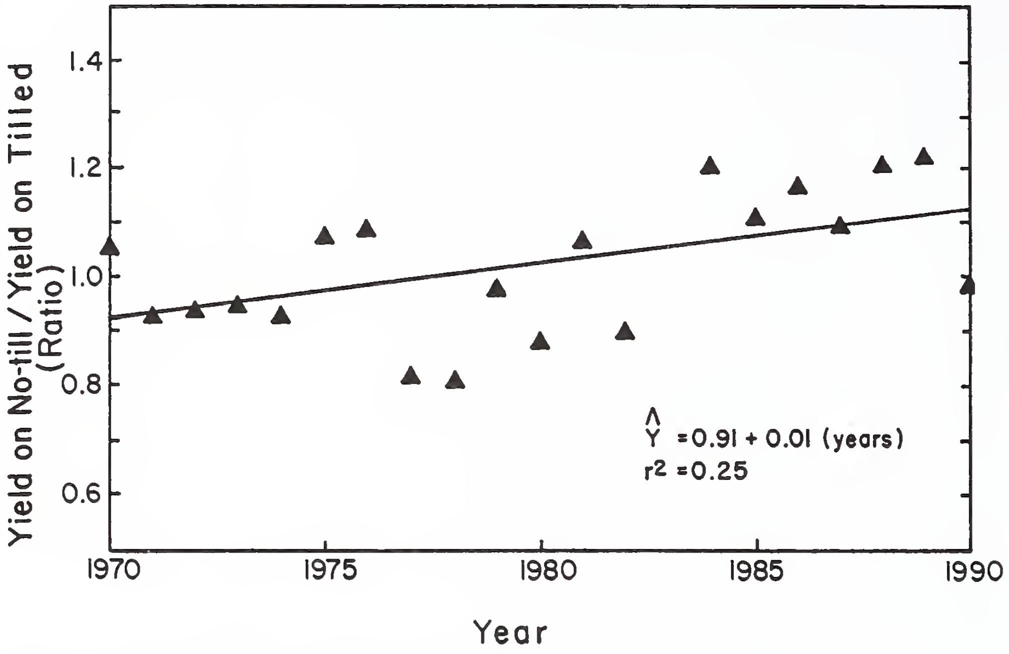


Figure 7. Long-term trends in corn yields under no-till compared to those under tilled management. Source: Ismail et al. 1994.

17 Success Cases in Crop Residue Management

Alabama: Brown and Harden Families, Southern Coastal Plain, MLRA 133A—M.S. Gillespie

Conservation tillage has been a familiar farming system at the Harden family farm in Banks, AL, since 1972. Jerrell Harden stated that they began experimenting with the system because they were looking for an economical way to farm. Today he continues to use conservation tillage and is still looking for ways to improve. The Harden system combines subsoiling and strip-tillage.

In 1972 Jerrell Harden began by growing corn and soybeans by strip-tillage. He liked the idea of subsoiling in the Coastal Plain to allow roots to capture moisture and nutrients from soil below the plowpan. In order to accomplish this, he developed his own planting system by attaching a set of subsoiler shanks to a conservation-tillage planter. He planted 200 acres in 1974 with the adapted equipment, with excellent results. In 1975, the Hardens arranged with Brown Manufacturing Co., Ozark, AL, to produce a coulter in-row subsoiler on a commercial scale. This equipment has a tool bar and subsoilers to penetrate the plowpan. It includes fluted coulters to till the subsoiler slots and to prepare a narrow seedbed. This tillage arrangement became known as the strip-till method.

In 1981, he began producing peanuts by the strip-till method and for the past 8 yr has grown his 400 acres of peanuts by this method. He also grows 450 acres of cotton by this method.

Harden's vision and innovative use of conservation tillage has helped revolutionize the system across the southeast. He has given demonstrations and participated in seminars across the country and on his own farm.

Jerrell Harden has greatly influenced the use of conservation tillage in the Atlantic and Gulf Coastal Plains of the southeastern United States. He has worked with researchers, extension workers, and soil conservation technicians as well as individual farmers in the development of equipment and techniques to plant crops by the strip-till/in-row chisel/subsoil method of conservation tillage.

Alabama: Shedd Family, Sand Mountain, MLRA 129—M.S. Gillespie

Lonnie J. Shedd, a farmer in Holly Pond, AL, described his plowpan Sand Mountain soil as follows: "The ground was hard, and we could not get a plow in it before strip-tillage. Now that all that residue has rotted, the soil is loose and easy to work." He and his sons, Chris and Garey, decided in 1987 to plant all their cotton in the strip-till system. They sold their conventional equipment within 2 yr.

Each year their yields have increased. "Our yields have not come under a bale since we started 7 yr ago. We never made that much before we started strip-tillage," stated the elder Shedd. Their system includes 2-yr rotations of cotton, soybeans, and a small grain.

Shedd shares his strip-tillage experiences with neighbors and others who visit his farm and at field days and conservation-tillage conferences.

Arkansas: Wiggins Family, Southern Mississippi Valley Alluvium, MLRA 131—L.D. Farris

Wayne Wiggins and his son, Wayne Wiggins III, grow corn, rice, soybeans, and wheat on their 2,000-acre farm at Egypt, AR, in the Promised Land Township. Wayne Wiggins has farmed there since 1964 and has been a conservation-tillage farmer for the past 7 yr.

Wiggins lends his enthusiasm and expertise to the conservation cause. He is convinced that crop residue management makes money. Like former Soil Conservation Service Chief William Richards, Wiggins started no-till farming "to save money and sustain crop yield." He stated that the main benefit to him has been economic because he has never had an observed soil-erosion problem.

Wiggins summarized his experience with conservation tillage as follows: He has never failed to get a stand of anything he has planted; he has always been able to get satisfactory, economical weed control; and he has, in numerous side-by-side tests, obtained equivalent or superior yields, compared to those under conventional tillage. With humor, Wiggins concluded, "If you can't make no-till corn work, you need to run for public office, because farming is obviously not your thing."

Florida: Walter Vidak and Partners Farm, Southern Coastal Plain, MLRA 133A—R.N. Gallaher

Surface-crop-residue management offers savings in soil and money on a 1,700-acre operation near Tallahassee, FL. Walter Vidak, a partner in Pascua Florida Corporation, has used conservation-tillage practices successfully on his farm since 1980. Vidak also uses 13 center pivots to irrigate the entire 1,700 acres with treated wastewater from the city of Tallahassee. One of the typical soils on the farm is Kershaw sand with a 5–8 percent slope.

Vidak practices triple cropping management over most of the 1,700-acre farm. One of his major triple cropping systems includes ryegrass or rye for winter pasture succeeded by corn for grain succeeded by soybean—all grown in a 12-mo period. Because of water management problems, many of the center pivot fields are split into two equal areas: one for row crops and the other for perennial grass. With this scheme, they hope to better manage the wastewater to achieve higher quality grain crops.

According to Vidak, their typical multiple cropping rotation might include planting corn in early March into a winter pasture, which may be rye or ryegrass. He further stated, "Because we have irrigation, we plant a group-nine (late maturing) soybean no-till planted immediately behind the corn harvest, usually in late July or early August. A group-nine soybean is risky for this area because it matures so late and is susceptible to damage from an early frost. I would not recommend planting it if you don't have irrigation. After the soybeans mature, usually in mid-November, ryegrass is oversown by airplane. We usually get the soybean off before the grass gets too tall. This gives us a 3- or 4-wk headstart on pasture growth."

Vidak described as follows their conservation residue-management tillage rig that attaches to the tractor in front of the planter: "First, we have a coulter that slices the ground. A parabolic subsoiler shank, mounted behind the coulter, shatters the hardpan. Two fluted coulters on either side of the shanks firm the subsoil area. Behind them, a rolling basket pulverizes the soil to provide a smooth seedbed for the planter. In addition to planting corn or soybean seed, the rig applies insecticide, nematicide, starter fertilizer, and micronutrients."

Vidak continued, "As a result of our continuous conservation tillage, we've encountered some problems with rodents—primarily field mice—that hide from predators in the mulch left on top of the ground. Sometimes we have to use repellants on our seed to prevent rodents from eating them. The best way we've found to control these pests is to destroy their hiding places by harrowing the mulch between some crops during the year."

"We've been using no-tillage on corn and soybean since 1980 and getting good yields. This should be of interest to growers throughout the region. I believe cotton and peanuts can be grown in this manner too," Vidak concluded. "Most people are still preparing their seedbeds conventionally by chiseling, plowing, and/or harrowing the ground and then working it several times in preparation for the planter. With my crop-residue management system, there's only one tractor trip across the field when it's planted. This system drastically cuts down on field time. We've been able to save many tractor trips across the field, thereby reducing our labor and equipment costs. It all adds up to a savings of around $20-$30/acre."

Vidak stated, "This system has a place in every operation. However, I do not recommend placing 100 percent of your acreage in no-till the first year. It should be a gradual process based on your own experience and that of others. One thing you have to remember is that no-tillage requires a higher level of management."

Georgia: F & W Agriservices, Inc., Southern Coastal Plain, MLRA 133A—P.K. Wilkerson

The Southern Coastal Plain of Georgia presents many challenges in surface-crop-residue management. Variations in soil, topography, climatic conditions, and weed and insect pressures made it difficult to manage crop residues without tillage until recent technology became available.

Many producers have now begun to practice no-tillage techniques with good success with cotton and peanuts. One of these producers is F & W Agriservices, Inc., based in Albany, GA. F & W is a total agricultural land-management firm that has a farm-management philosophy of placing each acre in its highest and best use (in crops, forestry, and livestock combinations), to maximize profit for the landowner. The firm applies conservation practices that are acceptable, workable, and affordable.

F & W began managing most of its farms in the southeast in 1985. It recognized that crop residue management is one of the best and cheapest conservation practices. It started by using a crop-residue management system that left 30 percent of crop residue on the soil surface following the planting of crops. At the same time, the firm began evaluating no-tillage and other practices on small acreages of corn in 1985 to identify the best method for successful corn production. It now plants 2,500–3,000 acres of corn using no-till management each year, with average yields over 200 bushels/acre.

No-till corn experiences led to 50 acres of cotton without tillage in 1987. This acreage was increased to over 5,000 acres of no-till cotton in 1992, with both 30- and 38-inch row spacings. Average yields of lint per acre are 1,200–1,400 lb.

F & W began no-till peanuts in 1991 with the same learning process on 20 acres. Yields equaled or exceeded conventional planted peanuts. For the 1992 planting season, the firm had about 200 acres of no-tilled peanuts.

F & W's current crop rotation consists of 3–4 yr of no-tilled crops (corn and cotton) followed currently with conventional-tilled peanuts. All surface-crop-residue-management acres are under center pivot irrigation.

Equipment used by F & W is designed for no-till planting. This consists of a planter unit with a coulter followed by an in-row subsoiler shank and double disk openers (strip-till modifications). Another essential piece of equipment is the shielded sprayer used in postemergence herbicide treatments of weed escapes.

F & W uses crop residues on the surface as a way of conserving soil and water and of recycling plant nutrients. New techniques are frequently adapted. An example of this technology is the way cotton stalks are cut following harvest. F & W has found that leaving cotton stalks 6–8 inches tall tends to trap residue in each row and also catches residue in natural drainageways and allows each row to act as a "residue dam." Planting cotton on the contour and using this method of stalk cutting has proven very successful on fields labeled highly erodible. F & W has been able to eliminate the need for expensive terraces and waterways by using surface-crop-residue-management farming methods in conjunction with grass buffer strips and contour farming.

F & W's experience with no-tillage as a crop-residue management tool has provided many benefits. Economics is a driving factor. F & W's system has allowed it to cut production costs such as labor and fuel needs. The savings on equipment repairs alone are about $20 per acre, compared to the previous conventional farming techniques.

In summary, F & W's experience with crop residue management has paid dividends in reduced weed pressure, reduced need for supplemental irrigation, reduced equipment cost, increased crop yields, and reduced soil loss on erodible land to acceptable levels. Off-season months are now spent in maintaining equipment and organizing materials in preparation for the next year's crop. F & W believes it is not "beating its land to death" by preparing the land for next year's crop with destructive conventional tillage. Its particular approach to crop residue management is proving to be effective in southwestern Georgia. This system of farming is providing benefits to the firm and to the environment.

(Information for this item was provided by the following persons from F & W Agriservices, Inc.: Dennis Barrentine, Vice President; Doug L. Pope, Soil and Water Conservation Consultant; and Lamar Hardigree, Crop Specialist, F & W Agriservices.)

Georgia: Rabbit Ridge Farms, Ronnie Everidge, Southern Coastal Plain, MLRA 133A—P.K. Wilkerson

Ronnie Everidge initially tried no-till in his soybean and corn farming operation about 20 yr ago but was never completely satisfied with the system. When about 1,150 acres of his farming operation in southern Georgia were designated as highly erodible, he knew that management changes were essential. This stimulated a closer look at surface-crop-residue management for his cotton and peanut rotations.

In 1992 Everidge switched from conventional tillage to a crop-residue management system on 800 acres of cotton and 400 acres of peanuts. This change from conventional-till to no-till meant a change in equipment as well as in planting and management techniques. He purchased the Brown-Harden Row Till unit (in-row subsoil chisels) and equipped it with John Deere Maxemerge II planters. He also purchased the Brown high-residue cultivator for use in weed control.

For the 1992 crop year, Everidge's cotton yields of 2.5–4 bales/acre and peanut yields of over 2,5000 lb/acre exceeded the average yields in Dooly County, GA. He noted a major reduction in tillage cost, as trips across his field with the tractor and other equipment were reduced from six to one.

His philosophy is that you must treat the whole crop-residue management system "as if you want to make a crop from the start." This includes doing the initial planning the year before the next crop. His planning begins immediately after the crop is harvested. A small-grain cover crop is planted either by airplane or by using a no-till grain drill. Weed control begins with a burndown herbicide applied aerially to the cover crop. Fertilizer is applied at recommended rates as required by soil test.

Everidge is convinced that his crop-residue management system will help him meet conservation compliance on his highly erodible land. He has noted three keys for successful no-tillage in a system like his: Obtain the right equipment, subsoil the cotton middles before the next season, and begin weed control early in the fall. Everidge stated, "The system will work if you want it to, but you have to get your mind set that you are not going to primary till."

Mississippi: King Farms, Blackland Prairie, MLRA 135—J.L. Golden

For generations, cotton has been the lifeblood of agriculture in Mississippi. Clean till cotton production has caused considerable soil erosion over the years. But Mississippi cotton farmers are now successfully producing no-till cotton on thousands of acres. This technique is spreading rapidly as more farmers reduce inputs, control the erosion, and maintain production.

Surface-crop-residue management can be a practical and relatively inexpensive way to help comply with the requirements of the 1985 and 1990 Farm Bills. In the process of trying conservation tillage to achieve the erosion control mandated in those bills, many farmers have learned that reduced tillage can save money as well as soil.

One Mississippi farmer, Bernard King of Leesburg, experimented with no-tillage in cotton 5 yr ago and now successfully uses it for his entire crop. In 1991 he planted 1,100 acres of cotton, all no-tilled. King stated, "Your soil, management abilities, and other factors must all fit together. It has worked well for us. Organic matter in some of our fields has doubled in 4 yr and we are also using less chemicals. Economics has done a lot to entice farmers into no-till. Conservation tillage is now used on over 90 percent of the cotton grown in Rankin County."

Chuck King, who farms with his father, said that they used to run a disk over the land twice, then a chisel plow, then row it up and drag it before planting. He stated, "Now I go in to spray and then plant it. Yields have increased, due at least in part to no-till. We've been averaging two bales or better."

North Carolina: Brooks and White Farms, Southern Piedmont, MLRA 136—B. Brock

Spurgeon Brooks, a dairy farmer in Stanley County, NC, first attempted no-tillage in the early 1970's and has steadily increased the acreage. Corn is planted in rye, crimson clover, hairy vetch, or soybean stubble. About 300 acres of corn are conservation tilled. Yields under irrigation have exceeded 200 bushels/acre on land that formerly produced 25–35 bushels/acre. This is not due entirely to no-till, but Brooks is convinced that surface-crop-residue management is essential for a successful soil management program.

The Brookses also plant about 400 acres of soybeans into crop residue from a small-grain and crimson-clover hay crop, as well as into barley and wheat residues. No-till alfalfa has also worked well on the Brooks' farm. No-till small grain has also been tried, with encouraging results. Brooks stated that surface-crop-residue management may not be suitable in all situations but that "it will work for the man that wants it to work."

The C.L. White family of Surry County, NC, uses a combination of stripcropping and no-tillage on a tobacco and grain farm. Strips are about 100 ft wide across the predominant slope. Alternating strips are planted with tobacco. The other strips are planted with small grain, followed by no-till soybeans. Every year, the crops are rotated; for example, the same strip is in tobacco one year, followed by small grain and double-cropped soybeans no-till the next year.

The Whites have used the strip system for over 20 yr. The land is of the Cecil-Pacolet type on slopes of 4–12 percent. Erosion rates are kept within tolerance. Tobacco yields have regularly exceeded county average yields by at least 400 lb/acre.

Tennessee: Milan Experiment Station, University of Tennessee, Southern Mississippi Valley Silty Uplands, MLRA 134—J.F. Bradley

No-tillage began at the Milan Experiment Station 25 yr ago under the influence of the late Tom McCutchen. McCutchen, a native of western Tennessee, had a burning desire to see the end of soil erosion. He was first told by university administrators to cease no-tillage research because "it would not work" and the university did not want to be associated with such an idea or experiment. McCutchen persisted and continued to interest University of Tennessee researchers.

The first research was performed in the area of agricultural engineering—work with planting instruments (planters and drills). This research was performed with coulters, furrow openers, and press wheels. Then came the research with herbicides for weed control. New uses for old herbicides were found, and several new herbicides that had come to the market were evaluated for no-till. McCutchen traveled extensively, reporting on the research at the Milan Experiment Station, gathering new ideas and learning how to improve crop-residue management methods.

In 1981, McCutchen hosted the first Milan No-Till Field Day to show farmers, producers, and agri-business people the latest in conservation-tillage research. Its basic format was research tours, equipment demonstrations, and commercial and educational exhibits related to practical and applied conservation crop production. He hosted two of these successful events before his untimely death at age 52, in June 1983. The annual No-Till Field Days have continued and grown with increased interest in conservation farm practices. In 1992, the event drew 6,200 people from 35 states and 11 foreign countries. Currently 128 research projects are being conducted at the Milan Experiment Station, of which 85 are directly related to no-till crop production. Research on surface-crop-residue management and conventional tillage is being conducted with corn, cotton, soybeans, grain sorghum, wheat, and cover crops. Presently the Milan Experiment Station research program is under the direction of John F. Bradley.

Studies are being conducted on cropping systems, rotations, tillage systems, row width, plant population, varieties, date of planting, fertilizer rates, source, and placement. Other studies are evaluations of soil and foliar diseases, soybean cyst nematode, soil and foliar insecticides and fungicides, plant-growth regulators, and herbicides.

In the area of soil conservation, studies are being run on the rate of erosion of different cropping systems, soil productivity, and runoff. In the agricultural engineering field, the Milan Experiment Station is researching low-volume sprayers, new planters and drills, fertilizer placement in conservation tillage, directed sprayers, and pesticide movement.

The attitudes of Milan Experiment Station's staff in developing no-till technology are as follows: that no-till is not for every field or every farmer but it has a place in today's agriculture; that no-till systems should be refined until the resulting crop production exceeds that of conventional tillage systems; and that inputs to the no-till system cost less than inputs to conventional systems.

The mission of the Station is to reduce soil loss in western Tennessee and to show the nation what can be done to conserve our most valuable resource: our soil.

Southern Conservation Tillage Conferences From 1978 to Present—G.W. Langdale

The University of Georgia organized and hosted the first Southern Conservation Tillage Conference at the Georgia Experiment Station in Experiment, GA, on November 29, 1978. A proceedings titled "The First Annual Southeastern No-Till Systems Conference" was edited by J.T. Touchton and D.G. Cummins. This tradition has continued for 15 yr, rotating among the southern land-grant universities.

Data presented at these conferences are usually the very latest research results that have not yet completed the review and publication process of a scientific journal. These proceedings permit crop-residue-management technology transfer almost immediately without the delay of review. The proceedings also document the evolution of conservation-tillage technology during the past two decades. However, most of these results have been published later in several refereed agricultural-science journals.

The allocation of research budgets and resources by southern land grant universities, federal agencies, and industry for a sustained time indicates the importance of crop residue management in the southeast. This research thrust has also been enhanced by grassroot cooperative efforts among scientists of several disciplines in various levels of government, in industry, and in farming.

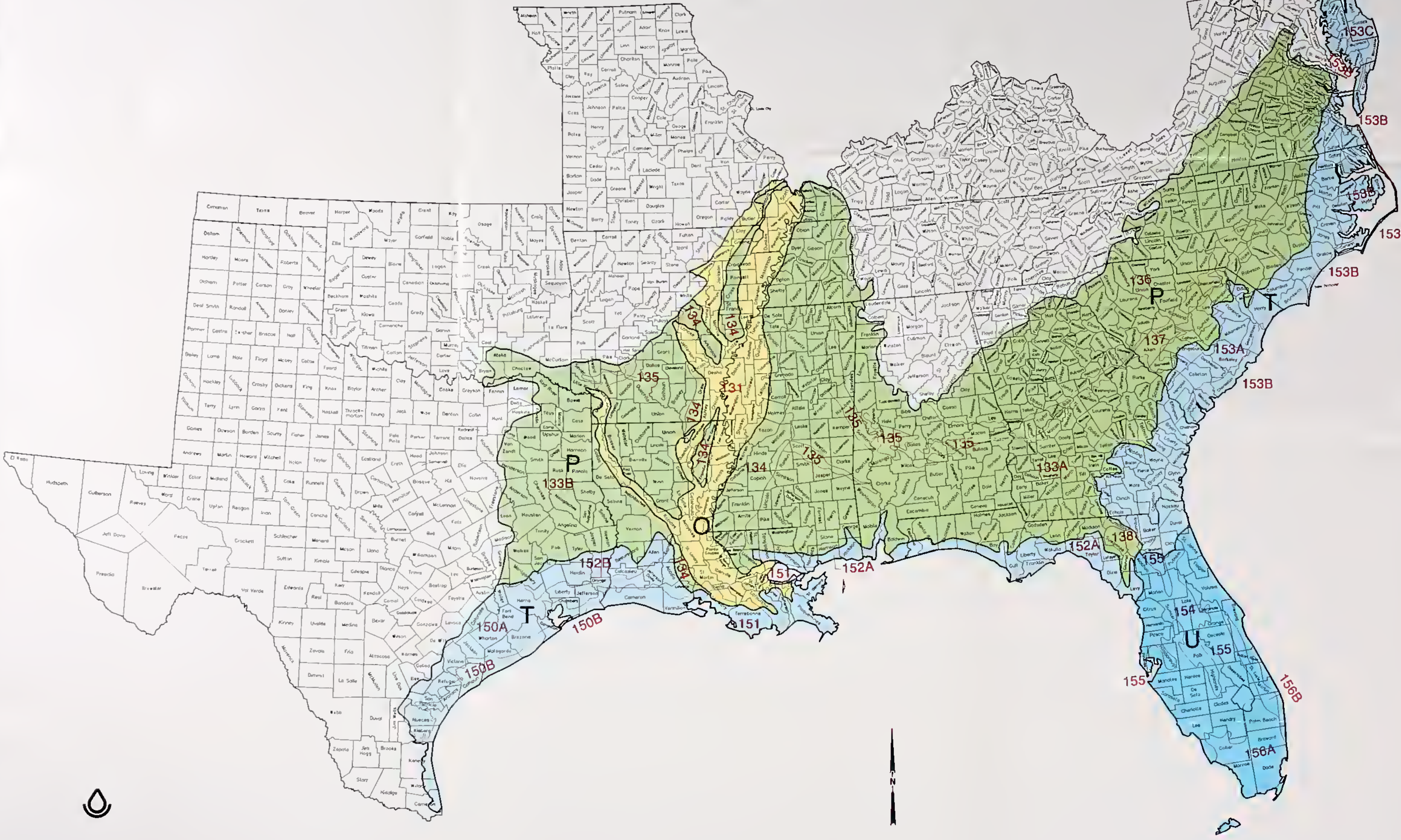
R.N. Gallaher of the University of Florida Experiment Station has volunteered to solicit and create a usable reference file of all published proceedings. The proposed library site for this proceedings collection is the Conservation Technology Information Center at Purdue University in West Lafayette, IN.

JANUARY 1994

U.S. DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

MAJOR LAND RESOURCE AREAS OF THE SOUTHEAST
(O, P, T, and U)



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